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Mitigation Options in the Transportation Sector

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EXECUTIVE SUMMARY

The transport sector—including passenger travel and freight movements by road, rail, air, and water—was responsible for about 25% of 1990 world primary energy use and 22% of CO_2 emissions from fossil-fuel use. It is one of the most rapidly growing sectors. Energy use in 1990 was estimated to be 61–65 EJ. Without new measures, this might grow to 90–140 EJ in 2025. Confidence in this range, and in the outlook for relative contributions of different countries, is low, and future transport energy use will be influenced by government policy. Nevertheless, industrialized countries are expected to continue to contribute the majority of transport-related greenhouse gas emissions until 2025. After 2025, the majority of transport-related emissions may be from countries that are currently developing rapidly or that have economies in transition.

Transport activity increases with rising economic activity, disposable income, access to motorized transport, and falling real vehicle and fuel costs. Societies are becoming increasingly dependent on the car for routine travel, aircraft for long distance travel, and the truck for freight transport. Transport activity, the development of urban and other infrastructure, lifestyles, and patterns of industrial production are all closely interrelated. As well as being linked to economic development, the transport sector imposes burdens on society, including the effects of traffic congestion, accidents, air pollution, and noise. Climate change is currently a relatively minor factor in decisionmaking and policy in the sector, although this could change in the future.

Greenhouse gas emissions could be reduced in all transport modes through changes in vehicle energy intensity or energy source, stimulated by research and development as well as by changes in current patterns of intervention in the markets for vehicles and fuels:

- Improved vehicle energy efficiency might reduce greenhouse gas emissions per unit of transport activity by 20 to 50% in 2025 relative to 1990 without changes in vehicle performance and size.
- If users were prepared to accept changes in vehicle size and performance, transport energy intensity could be reduced by 60 to 80% in 2025.
- With energy-intensity reductions, the use of alternative energy sources could, in theory, almost eliminate greenhouse gas emissions from the transport sector after 2025. A complete transition to zero greenhouse gas emission surface transport is conceivable but would depend on eliminating emissions throughout the vehicle and fuel-supply chain.

In all cases, there is medium confidence in the ranges for these technical potentials, which depend on government policies and decisions made by vehicle and energy suppliers.

The use of motor vehicles might be reduced by changing land-use patterns and lifestyles to reduce the need for goods transport and travel; restrictions on the use of motor vehicles; and fiscal or other measures to discourage motor vehicle use and to encourage the use of nonmotorized transport. No confidence can be placed in estimates for the ultimate potential mitigation through these measures. A few city authorities have used packages of such measures to control traffic and have reduced energy use by 20 to 40%.

Travel-mode switching from car to bus or rail can reduce primary energy use by 30 to 70%, while switching container freight traffic from road to rail can reduce primary energy use by 30%. The percentage of greenhouse gas emission reduction is more than this value if railways are powered with electricity from nonfossil sources. Confidence in the potential for mitigation through mode switching is low because human behavior and choice play a central role, and these factors are poorly understood.

Experts may not agree on the best approach among these options and sometimes give conflicting advice. Nevertheless, there is an emerging consensus that attempts to move traffic to less energy-intensive modes depend on using well-integrated strategies designed specifically for local situations. Measures to encourage nonmotorized transport and public transport tend to work only when combined with measures to reduce the distances people need to travel and discourage energy-intensive vehicle use. Several cities in Latin America, Southeast Asia, and Europe have succeeded in stemming the growth in car use by such combined strategies.

In many circumstances, strategies may not be implemented if they might reduce the benefits provided by transport systems to individuals and firms. Greenhouse gas mitigation strategies will have to address this issue and find ways to meet or change the needs and desires currently met by energy-intensive transport. Preferences in travel behavior are driven by social and cultural factors, as well as by cost-effectiveness in meeting needs.

Policies with a wide variety of social, economic, and environmental objectives—especially those of reducing traffic congestion, accidents, noise, and local air pollution—also can reduce greenhouse gas emissions from transport. Conversely, greenhouse gas mitigation strategies are likely to be more acceptable

and successful if they are integrated into wider strategies in transport, urban development, and environment policy.

Appropriate mixes of policies will vary between cities and countries. In small towns with relatively simple infrastructure, provision for nonmotorized transport and alternatives to transport may be particularly important. Cities with rapidly developing infrastructure have an opportunity to manage transport-system development, ensuring the viability of nonmotorized and public transport modes. In countries and cities with highly developed infrastructure and technical capability, changes in the transport system are likely to be slower but may hold more potential to influence vehicle technology and energy sources.

When considering transport-sector mitigation options in engineering, economic, or planning terms, it is important to recognize that there are simplifying assumptions in these three frameworks, so each gives an incomplete picture. None incorporates an accurate understanding of human behavior and choice, although these are essential determinants of greenhouse gas emissions from the sector. Policymakers can address these issues by developing mechanisms and institutions to inform and educate transport stakeholders and involve them in the design and implementation of mitigation strategies.

There are several factors that lead to inertia in the development of transport systems: Technologies and fuels now in the laboratory can require several decades for commercialization; transport infrastructure is developed slowly and has an influence that can last for centuries; stakeholders may be reluctant to change their practices; and transport user behavior and choice also may develop slowly in response to a changing environment. Once transport systems are developed to service the car, truck, and airplane, it is very difficult to reverse the shift away from nonmotorized and public transport. Some immediate actions can be taken to facilitate future mitigation strategies; for example, new infrastructure can be designed to allow for nonmotorized transport. Greenhouse gas mitigation strategies could take some years, even decades, to deliver results and will have to be implemented long before anticipated greenhouse gas reduction needs.

21.1. Introduction

This chapter addresses options for mitigation of greenhouse gas emissions in the transport sector, which includes all types of travel and freight movement by road, rail, air, and water. Fluids—mainly petroleum and natural gas—are moved by pipeline, but greenhouse gas mitigation in pipeline systems is treated in Chapter 19.

Section 21.2 analyzes current emissions of greenhouse gases from transport and their trends, looking at road, rail, water, and air; the contribution of non-CO_2 greenhouse gases; and the patterns in different countries and regions. Section 21.3 reviews the potential for emission reductions through changes in vehicle maintenance and new vehicle design, through changes in vehicle operating practice, and through the introduction of alternative fuels. It also discusses the long-term potential for electrically powered transport and identifies key areas where research and development are needed. Section 21.4 reviews the effects of fiscal, regulatory, planning, and other measures in the transport sector and aims to clarify some of the differences of opinion among experts on the desirability and feasibility of measures.

21.2. Transport and Greenhouse Gas Emissions

21.2.1. Current Emissions

Greenhouse gas emissions from transport result mainly from the use of fossil fuels; the main greenhouse gas produced is CO_2. The transport sector was responsible for about 25% of 1990 world primary energy use and 22% of CO_2 emissions from energy use (including energy use in fuel production; based on IEA, 1993c). These shares are growing in almost all countries. Rising incomes and steady or declining fuel costs have encouraged a 50% growth in world energy use in the sector between 1973 and 1990—an average of 2.4% per year (Orfeuil, 1993). The 65 EJ consumed by transport, including

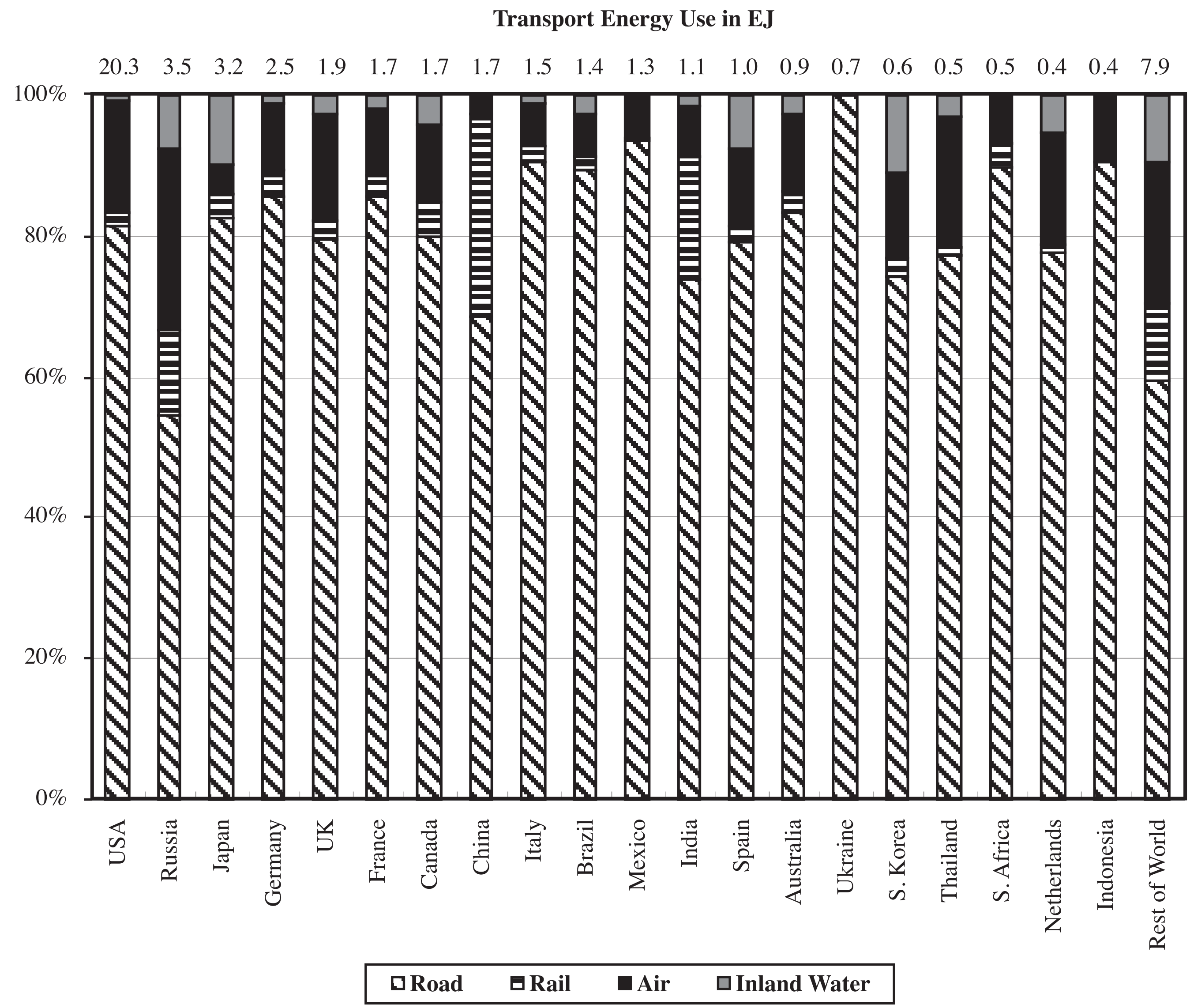

Figure 21-1: Transport-fuel sales, 1990, EJ (IEA, 1993c; Pischinger and Hausberger, 1993).

marine bunker fuel, in 1990 represented 58% of all oil products consumed (IEA, 1993c).

In 1990, about 23 countries' transport sectors are thought to have consumed more than 0.42 EJ in final energy, excluding marine bunkers. Figure 21-1 shows transport-fuel sales, excluding marine bunkers, in the 20 of these countries for which detailed data are available (IEA, 1993c, 1993d). In these countries, road traffic uses roughly 80% of total transport final energy consumption, air traffic 13%, rail 4.4%, and inland water transport 2.6%.

Given the large road-transport share of energy use, greenhouse gas mitigation options discussed in this chapter will focus on this subsector, although some options for air transport also will be addressed.

While CO_2 is the main greenhouse gas emitted by the transport sector, emissions of non-CO_2 greenhouse gases add to the radiative forcing of vehicle emissions. In addition to nitrous oxide (N_2O), methane (CH_4), and chlorofluorocarbons (CFCs), vehicles emit large quantities of carbon monoxide, volatile organic compounds (VOCs), and nitrogen oxides (NO_x) for which global warming potentials (GWPs) are not currently available (see IPCC Working Group I volume, 1995). N_2O contributes about 10% to the radiative forcing of tailpipe emissions of gasoline cars equipped with three-way catalytic converters (based on CEC, 1992; Prigent *et al*., 1991). Greenhouse gas emissions during car manufacture and disposal add a further 10 to 15% relative to tailpipe CO_2, while releases of CFCs (used mainly in air conditioning) add between 10 and 50%. CO_2 and CH_4 emitted during oil exploration, extraction, processing, and transport contribute 10 to 20% of overall life-cycle forcing caused by vehicles using petroleum products (IEA, 1993a; CEC, 1992; DeLuchi, 1991).

The radiative-forcing effect of non-CO_2 emissions from aircraft engines is very uncertain. In particular, the impact of NO_x emitted at altitudes where subsonic aircraft fly could be more important than equivalent NO_x emissions at the Earth's surface. The effect of aircraft NO_x is uncertain: It could be of similar magnitude or smaller than the effect of CO_2 from aircraft (see Chapter 2.2, *Other Trace Gases and Atmospheric Chemistry,* in the IPCC Working Group I volume). Aircraft also emit carbon monoxide, water vapor, soot and other particles, sulfur gases, and other trace constituents, which have the potential to cause radiative forcing, but the impact of these emissions has not yet been properly assessed.

21.2.2. Projections of Transport Greenhouse Gas Emissions

At least until 2025, CO_2 is likely to remain the main greenhouse gas produced by the transport sector, and emissions will depend mainly on energy use in the sector. Several scenarios of transport energy use to 2025 have been developed; some are shown in Figure 21-2. All of these projections are produced based on some set of assumptions regarding the continuation of historical relationships between transport fuel consumption and variables such as gross domestic product (GDP), fuel prices, and vehicle energy efficiency.

International comparisons reveal a strong correlation between transport energy use and GDP. (The data plotted in Figure 21-3 indicate a GDP elasticity of 0.89, with $R^2 = 0.93$.) Nevertheless, at a given level of GDP, energy use can vary by a factor of two. The growth of transport with income and time is faster for middle-income countries than for very-low-income countries (Button, 1992). Button developed a model for car ownership that has been used by Orfeuil (1993) to indicate that, by 2020—assuming current GDP growth trends continue—developing countries will have a third of the world's car fleet, compared with 14% today.

Many analysts have found a close correlation between road-freight traffic (tonne-km) and GDP (Bennathan *et al*., 1992), whereas rail freight appears to be almost independent of GDP but is very closely related to country surface area.

Figure 21-4 plots national average road-transport energy use per unit of GDP against fuel prices. It shows that prices may help to explain some, but by no means all, of the variation in energy use per unit of GDP. Variations also may be explained partly by geographic, cultural, and other factors.

Many analysts have criticized the use of historical relationships between the economy and energy use to produce projections. Although car ownership is growing very rapidly in Europe and Asia, Grübler and Nakicenovic (1991) suggest that it may saturate at lower per capita levels than in North America. In this case, global car energy use may not be much higher in 2010 than it was in 1985, assuming that fuel economy continues to improve at historical rates.

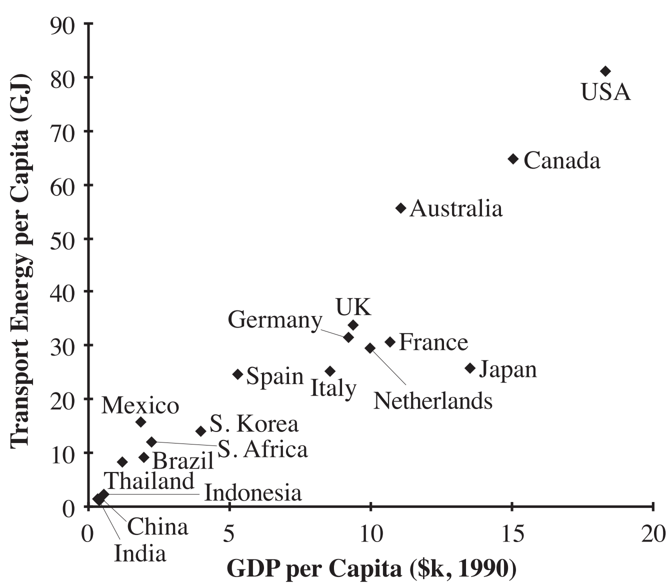

Figure 21-3: Total transport energy use vs. gross domestic product in 1990, for 18 of the world's largest transport energy users. Excludes Russia, Ukraine, Iran, Saudi Arabia, and Kazakhstan; former West and East Germany data have been combined (IEA, 1993c, 1993d).

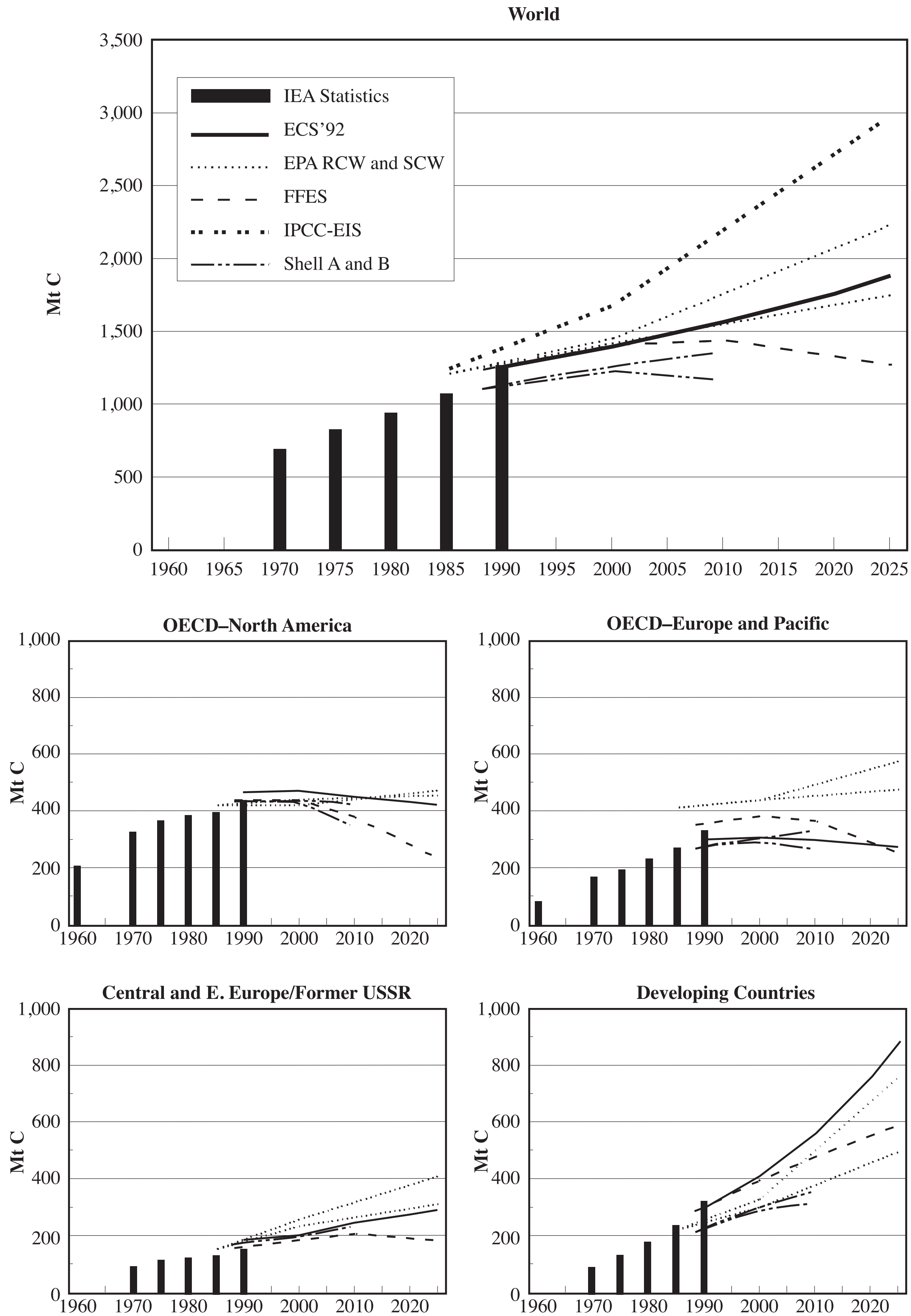

Figure 21-2: Comparison of transport CO_2 emission scenarios to 2025 (Grübler, 1993). Note: IEA = International Energy Agency; ECS = Environmentally Compatible Energy Strategies; RCW = Rapidly Changing World and SCW = Slowly Changing World; FFES = Fossil-Free Energy System; and EIS = Energy Industry System.

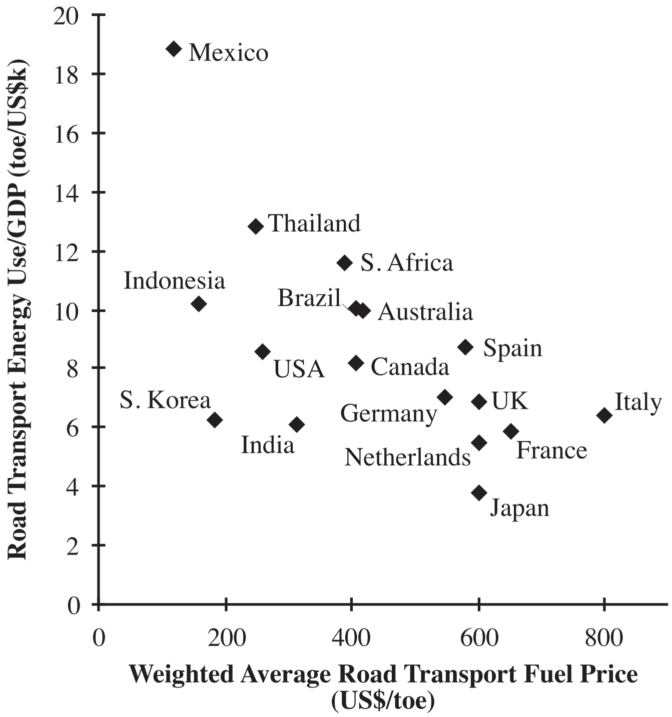

Figure 21-4: Road transport energy per unit of GDP vs. average fuel price in 1990, for 17 of the world's 20 largest transport energy users. Excludes China, Russia, and Ukraine; former West and East Germany data have been combined (IEA, 1993c, 1993d, 1994a; ADB, 1994).

21.2.3. The Role of Transport

Transport is needed for basic survival and social interaction as well as cultural and economic activity and development. Transport systems develop with the socioeconomic situation and the land-use patterns in which they are embedded (Dimitriou, 1992). Climate change is a new concern to be added to the many influences and interests in the transport sector; some of these influences and interests may support the aim of reducing greenhouse gas emissions, while others may be in conflict with it.

People use transport to travel between homes, workplaces, shops, and services; to socialize; and to take vacations. As travel becomes quicker, more flexible, and cheaper, people's options (where to live, work, shop, and socialize) broaden. Some people can use increasing mobility to improve their economic situation and quality of life. For others, especially the poor—particularly those in rural areas—the lack of affordable transport remains an economic and social constraint.

Producers of goods use transport systems to gain access to raw materials and to their markets. As the quality of transport improves and costs fall, the production and distribution of goods becomes cheaper and more efficient. Firms have increasing flexibility in their sources of raw materials and the markets for their products; they have a greater choice of production locations and employees; they also can become more specialized, achieving economies of scale and taking advantage of local conditions suited to their activities.

Transport systems can become an end in themselves; this is perhaps most obvious in the case of the automobile, which has become a symbol of wealth and social status. Tengström (1992) explores the extent to which this technology has shaped modern culture and provides a review of the related literature.

The uses to which transport services are put evolve as incomes rise, costs fall, and priorities change. A number of stages in the use of transport systems can be identified, corresponding roughly to Maslow's hierarchy of needs (Maslow, 1954):

1) Essential survival needs: movement of food, fuel, water, and travel for health care and to escape danger
2) Needs relating to economic security: movement of traded goods—mostly primary commodities—and travel to work and for education
3) Needs relating to social involvement: visiting family and friends, travel to entertainment, and family vacations; goods transport moves beyond essentials to include more manufactured goods
4) Needs relating to self-expression and exploration: tourism and more distant vacations; goods transport moves toward very high value-added goods.

This pattern is reflected in transport statistics and travel surveys, which indicate that, as societies become wealthier, social and leisure travel become more important. The car has been an essential element in this process, allowing increasing flexibility, especially in social relationships. The development of air travel has allowed tourism to flourish.

Transport demand was, until recently, seen in most countries as a social and economic need to be met. At the same time, growing motorized transport use has long been recognized to have negative consequences for society. The most important of these include:

- Traffic congestion
- Accidents
- Noise, vibration, and air pollution
- A wide range of social problems related to the use of land, reduction in nonmotorized transport use, reduction in availability of local services, and so forth, contributing to a declining quality of life for non-car owners.

Measures designed to address these issues provide the main opportunity at present to reduce greenhouse gas emissions from transport. Greenhouse gas mitigation policy is more likely to succeed if it addresses concerns such as these.

21.2.4. Activity and Energy Use in the Transport Sector—Travel Behavior

Table 21-1 shows information from a number of city travel surveys in Asia and Africa. The variation in travel patterns

Table 21-1: *How people travel—percentage of trips by mode in Asia and Africa.*

Country/City	Survey Year	Non-motorized	Private Motorized	Public Transport and Taxi
Asian City Surveys (Midgley, 1994)				
Low Income				
Tianjin	1987	91	–	9
Bombay	1981	26	9	65
Jakarta	1984	40	21	39
Middle Income				
Seoul	1982	12	8	80
Kuala Lumpur	1984	12	46	42
Bangkok	1984	16	24	60
High Income				
Central Tokyo	1988	24	25	51
Greater Tokyo	1988	22	54	24
African City Surveys (Davidson, 1993)				
Abidjan	1988	30	12	51
Dakar	1989	50	17	32
Nairobi	1989	15	25	50
Conakry				
Low Income		55	3	41
Middle Income		27	19	54
High Income		5	57	38

among cities in Asia, even at similar income levels, is quite striking and is much greater than the variation among countries within Europe, for which survey results are provided in Table 21-2. Despite the upward trends in most motorized forms of transport, walking and cycling continue to provide a large proportion of mobility and access needs in many countries.

Several observations can be made based on the European data. First, the variation among countries in distance traveled per day (standard deviation 16% of mean) is about twice as large as that in the number of trips and the time spent traveling (8 and 9%, respectively). It might be concluded from this type of data that (1) people travel to satisfy a certain number of access needs (for work, services, etc.) that do not vary significantly as the transport system changes, and (2) people operate with a time budget and will spend roughly the same amount of time traveling during each day, regardless of the average speed of the transport system. This would imply that measures that make travel faster will tend to increase the distance traveled by people.

Second, in most countries (with the exception of the United Kingdom), public transport is used for longer trips than cars: The public-transport share of trips is smaller than the share of distance. This has been confirmed by other studies (e.g., Birk and Bleviss, 1991). Walking, cycling, and moped trips, not surprisingly, are shorter on average than public-transport and car trips in all countries.

Third, although the car dominates the distance traveled in all countries, the car share of trips is about equal to the share of trips on foot, bicycle, or moped. Thus, although cars appear to dominate European transport according to the distance traveled, they are about equal in importance with travel on foot and on two-wheelers according to the number of trips.

Global road-vehicle fleets grew 140% between 1970 and 1990 (OECD, 1993a). The vehicle population could increase by anything from 60 to 120% by 2025, and 140 to 600% by 2100 (Walsh, 1993b; see Table 21-3). The current annual percentage growth is highest in Southeast Asia, Africa, Latin America, and

Table 21-2: *Daily travel of Europeans according to travel surveys (Salomon et al., 1993).*

				Daily Mean for Respondents			Modal Split (trip/distance-based)			Split by Purpose (trip-based)		
Country	**Survey Year**	**Age Range (yrs)**	**Period Surveyed**	Trips (#)	Distance Traveled (km)	Time Traveling (min)	Walk, Bike, Moped (%)	Public Transport (%)	Car (%)	Work, Education (%)	Shopping, Escorting Children (%)	Social, Leisure (%)
Austria	1983	>6	Weekday	2.9	22	67	40/8	19/34	42/58	40	30–41	18–29
Finland	1986	–	7 day	3.1	–	71	31/6	12/19	57/75	33	34	33
France	1984	>6	7 day	3.1	21	53	41/8	8/17	51/75	38	36	26
Former West Germany	1982	>10	7 day	2.9	30	69	41/8	14/25	45/57	39	32	30
Israel	1984	>8	Weekday	3.0	–	–	37/–	31/–	32/–	43	28	29
Netherlands	1987	>12	7 day	3.4	33	71	47/16	5/12	47/72	29	25	46
Norway	1985	13–74	7 day	3.4	32	71	35/6	11/31	54/63	33	22	45
Sweden	1983	15–84	7 day	3.6	25	–	38/5	12/20	50/70	36	16	48
Switzerland	1984	>10	7 day	3.3	29	70	46/10	12/20	42/70	36	34	30
UK	1986	–	7 day	2.8	23	–	37/9	14/19	49/72	30	40	30

Table 21-3: Scenarios of world road vehicle population and traffic to 2100 (Walsh, 1993b).

	Vehicle Population (million vehicles)			Traffic (trillion vehicle-km)		
Year	Cars and Light Trucks	Heavy Trucks	Two-Wheelers	Cars and Light Trucks	Heavy Trucks	Two-Wheelers
1990	540	30	110	3.5	0.5	0.3
2030	910–1300	60–90	180–250	5.8–8.2	1.1–1.5	0.5–0.7
2100	1200–3800	110–380	250–800	8.1–24.3	2.0–6.7	0.7–2.2

some central and eastern European countries. Much of the fleet growth in these countries comprises second-hand vehicles imported from the Organisation for Economic Cooperation and Development (OECD) countries, which still have the largest markets for new vehicles. Developing countries account for only 10% of the world's cars (Birk and Bleviss, 1991).

Light-duty vehicle traffic has risen rapidly in recent years with rising incomes and falling real costs of vehicle ownership and use, including fuel costs. The fastest growth has been in Southeast Asia, Africa, Latin America, and most recently in Central and Eastern Europe (Suchorzewski, 1993). Most countries have seen an increase in travel by bus and train from 1965 to 1991, although the growth has been less rapid than that in car traffic (ECMT, 1993; Schipper *et al*., 1993).

Two-wheelers, especially mopeds with two-stroke engines, are one of the most rapidly growing means of personal transport in parts of South and East Asia and Latin America (Dimitriou, 1992; IEA, 1994c). India has about four times as many two-wheelers as cars (UNESCAP, 1991), and the ratio is expected to increase. Three-wheelers are important means of transport in several Asian cities, where they often are used as taxis.

OECD countries have four cars to every goods vehicle; in non-OECD countries, the ratio is nearer to two cars to every goods vehicle. Goods transport by road rose more during the 1980s than did personal travel. An increasing share of goods transport in industrialized countries has been carried by smaller trucks, as high-value-added goods account for an increasing proportion of production and as the service sector, including retailing, grows faster than the rest of the economy. At the same time, bulk freight is becoming increasingly concentrated in very large trucks (around 40 tonnes gross vehicle weight).

The breakdown by type of vehicle of the 46 EJ of energy used for road transport in 1990 is poorly documented, but Walsh (1993a) estimates that goods transport is currently responsible for about 27% (see Figure 21-5).

Rail freight traffic has increased or remained fairly steady in most countries. Because rail freight is less flexible than road freight, it has tended to become confined to conditions where costs per tonne-km are lower than for road freight; rail terminals exist at, or good road/rail transfer facilities exist near, both the origin and the destination; speed is relatively unimportant; and shipments are regular. Rail freight is most important in large countries where long hauls are more frequent (Bennathan *et al*., 1992), including the United States, the former Soviet Union, and China. Its market has declined in many small countries. It also has declined as industries have moved toward "lean" manufacturing requiring fast, flexible, "just in time" transport systems. In central and eastern European countries, the process of economic reform also has brought about a large shift of freight from rail to road (GUS, 1993). Meanwhile non-motorized goods transport, which makes a negligible contribution in OECD countries, is important in developing countries, especially in rural areas.

Growth in air travel (passenger-km on scheduled services) has been much greater than economic growth but has been closely linked with it. The growth rate has declined, from 13.4% per year during 1960–1970 to 9.0% per year during 1970–1980 and 5.7% per year during 1980–1990 (ICAO, 1992). An increasing share of air passenger traffic is for leisure purposes. Air freight traffic (tonne-km on scheduled services) has grown

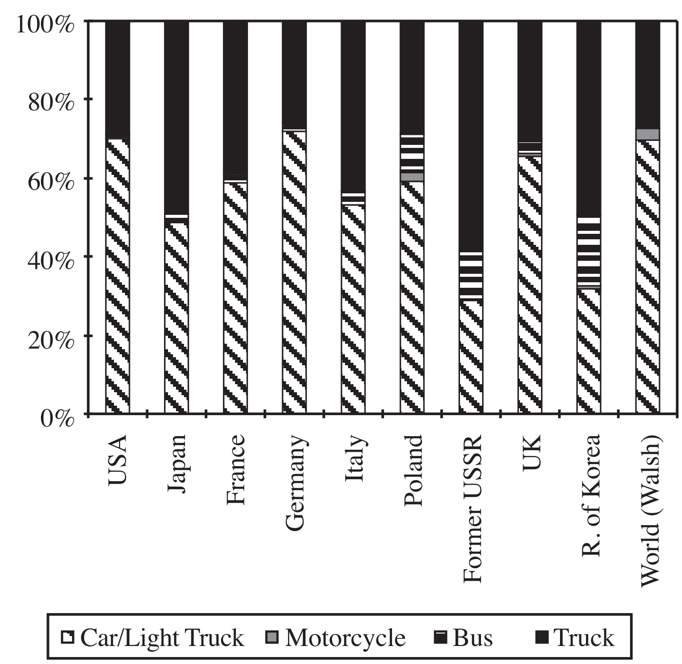

Figure 21-5: Shares of energy use by road vehicles, various years (Schipper *et al*., 1993; Pischinger and Hausberger, 1993; Walsh, 1993a; Kang, 1989).

more rapidly, at 11.7% per year during 1960–1990 (ICAO, 1992). Half of passenger traffic and about 80% of freight traffic is international (ICAO, 1994a).

Waterborne transport volumes—mostly bulk marine freight—have fluctuated with international trade in bulk commodities. Bulk marine freight grew from 25.3 billion tonne-km in 1981 to 28.8 billion tonne-km in 1991 (OECD, 1993b). Most traffic in 1991 was made up of crude oil and oil products (46%), coal (11%), iron ore (11%), and grain (6%).

21.2.5. Trends in Transport Energy Intensity

So far, this chapter has discussed trends in traffic by different transport modes. Greenhouse gas emissions from transport depend mainly on energy use, which is the product of the energy intensity (energy use per passenger-km or tonne-km) and the level of activity (passenger-km or tonne-km).

Table 21-4 provides estimates of the range of national averages of energy intensity for travel by car, bus, and train in various parts of the world. Differences between countries may be explained by a variety of interlinked factors, including age and design of the vehicle fleet, share of larger or higher-powered cars, quality of maintenance, and level of traffic congestion. All of these variables may be influenced by geographical, social, economic, and other factors.

There are competing influences on energy intensity. High-income countries in North America and Scandinavia have efficient technology but use it partly to provide a higher standard of transport services; vehicles of most types, including buses and trains, tend to be larger, heavier, and more comfortable. Low-income countries, such as China and India, tend to have less-efficient technology—but occupancies are relatively high, leading to low energy intensity. Indeed, average two-wheeler occupancy in Delhi, at 1.6 (Bose and Mackenzie, 1993; UNESCAP, 1991), is higher than car-occupancy levels in many industrialized countries, which can be as low as 1.2. Countries between these two extremes where transport activity is currently increasing rapidly (including southern and eastern European countries, Korea, and Japan) tend to have efficient technology that is used for lower standards of transport service, resulting in quite low energy intensities.

Car-occupancy levels in industrialized countries have declined with rising car ownership. Whereas buses and trucks in developing countries often are overloaded, leading to safety concerns, those in industrialized countries tend to have low occupancies or load factors, so operators and policymakers are concerned to find ways to increase loading.

For cars, there is an estimated 10 to 20% differential between national average on-road fuel economy and the results from official fuel economy tests (IEA, 1993a; Martin and Shock, 1989; Schipper and Tax, 1994). Differences arise because,

Table 21-4: *Passenger transport energy intensity—estimated national averages (Chin and Ang, 1994; Davis and Strang, 1993; Faiz, 1993; Grübler et al., 1993b; CEC, 1992; Schipper et al., 1993; Walsh, 1993a).*

Country/ Date of Estimate	Light-Duty Passenger Vehicles: Fuel Economy[a] (L/100 km)	Load Factor (# people)	Energy Intensity (MJ/pass-km)	Mopeds: Load Factor (# people)	Energy Intensity (MJ/pass-km)	Buses: Load Factor (# people)	Energy Intensity (MJ/pass-km)	Trains: Energy Intensity[b] (MJ/pass-km)
Sub-Saharan Africa, 1985	20–24	2[c]	3.2–3.8			35–60	0.2–0.33	
China, India, and Thailand, ~1990	11–14	2[c]	1.8–2	1–1.6	0.5–0.8	35[c]	0.35	
Singapore, 1992	9	1.7	1.7	1.2	0.7	n/a	0.6	1.2
Japan and Korea, 1991	10–11	1.4	1.5–1.6	1	0.7–0.8	20[c]	0.65	0.55
United States, 1991	13–14	1.5	2.6			14[c]	0.9	2.75–3.0
Western Europe, 1991	8–11	1.5–1.8	1.2–1.96	1	0.7–0.8	10–25	0.49–1.32	0.75–2.8
Poland, 1991	9	2	1.3	1	0.73	35	0.33	0.32–0.83
Former USSR, 1988	12[c]	2	2			20	0.6	

[a]Estimated gasoline-equivalent fuel consumption per vehicle-km for the national car fleet.
[b]Electricity as primary; efficiency of conversion from primary energy to electricity supplied to locomotives assumed to be 30%.
[c]Very uncertain.

among other things, cars usually are not tested with auxiliary equipment, such as air conditioning, in operation, and some tests do not include cold starts, which can result in excess fuel consumption as high as 50% for short trips in cold weather (Hausberger *et al*., 1994). In some regions, poor road quality may increase fuel consumption; that increase is an estimated 50% in Russia (Marchenko, 1993).

Car mass and engine size are closely related to energy intensity (Ang *et al*., 1991). An upward trend in these factors has been observed in several European countries and in Japan (IEA, 1991a; Martin and Shock, 1989). In the United States, a downward trend in engine size and car mass (Difiglio *et al*., 1990) has been reversed in recent years (NHTSA, 1994).

A more important factor in some countries is the expanding use of "light trucks"; these include small pickup trucks and minibuses. Light trucks accounted for 32% of the personal private vehicle market in the United States in 1990, and their fuel consumption per kilometer is about 36% higher than that of cars (Greene and Duleep, 1993).

The on-road mean fuel consumption per kilometer driven of light-duty passenger vehicles in North America fell by nearly 2% per year between 1970 and 1990, to about 13–14 L/100 km, but remains 30 to 40% higher than that in Europe or Japan (Schipper *et al*., 1993). In other industrialized countries, changes during the period were quite small (see Figure 21-6), although new-car fuel economy in official tests improved by about 20% during the period (IEA, 1993a).

Most of the cars sold worldwide are either new cars made to designs originating in the OECD or second-hand cars exported

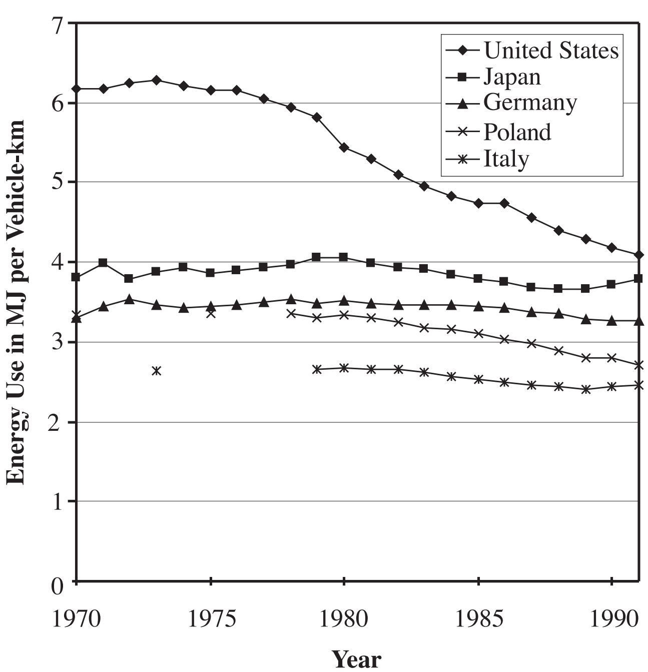

Figure 21-6: Light-duty passenger-vehicle energy intensity (MJ/vehicle-km) (Schipper *et al*., 1993).

from the OECD. Any changes in vehicle technology, therefore, tend to be driven by the requirements of OECD new-vehicle markets.

While car energy intensity in the OECD has fallen during the past 20 years, the energy intensity of car travel has increased in many countries as a result of declining car occupancy. Meanwhile, the more recent trend is toward higher energy intensity in new cars in countries including the United States, Germany, and Japan (IEA, 1991a, 1993a), and global average fuel economy will not necessarily improve in the near-term future. Nevertheless, projections often incorporate a reduction of 1 to 2% per year (Davidson, 1992; Grübler *et al*., 1993; IEA, 1991a, 1993a). This can vary considerably within regions: Davidson (1992) gives projections for African countries between 1985 and 2025 ranging from 0.6% per year in Sierra Leone to 1.8% per year in Nigeria.

Few estimates are available of energy intensity in aviation. Flights of 1,000 km or more typically have energy intensity in the range of 1.5 to 2.5 MJ/passenger-km. For short-haul flights, energy intensities can be higher than 5 MJ/passenger-km (ETSU, 1994). World civil air traffic (tonne-kilometers) increased by 150% between 1976 and 1990, while energy consumption rose by only 60%. This situation represents about a 3–3.5% per year reduction in energy intensity (Balashov and Smith, 1992), which is a result of improved aircraft energy efficiency and rising utilization of available seats and cargo capacity.

Walking and cycling only result in greenhouse gas emissions if people eat more food to compensate for the energy they use. This is of the order of 150 kJ/km for walking and 60 kJ/km for cycling (Banister and Banister, 1994; Hughes, 1991). Fossil-fuel use in agriculture, food processing, transport, storage, and cooking is highly variable but on average is of the same order of magnitude as the energy content of the food.

Data on the energy intensity of road freight traffic are hard to obtain and interpret in most countries. Energy use is typically in the range of 3 to 4 MJ/tonne-km on average and 0.7 to 1.4 MJ/tonne-km for heavy trucks (Schipper *et al*., 1993; CEC, 1992). In countries where services and light industry are growing faster than heavy industry, the share of small trucks or vans in road freight increases; these have high energy intensity compared with large trucks. Along with the increasing power-to-weight ratios of goods vehicles, these trends offset—and in some cases outweigh—the benefits of improving engine and vehicle technology (Delsey, 1991a). The energy intensity tends to be lower in countries with large heavy-industry sectors, where a high proportion of goods traffic is made up by bulk materials or primary commodities.

Average truck energy use per tonne-kilometer of freight moved has shown little sign of reduction during the past 20 years in countries where data are available (Schipper *et al*., 1993). Although vehicle technology has improved, this improvement has been used partly to increase the power-to-weight ratio of vehicles rather than to reduce energy use. The structure of the road-freight market has shifted in many OECD countries away from medium-sized trucks toward very large trucks for bulk freight and small trucks for retail distribution and high-value goods. Much of the recent growth has been concentrated in small trucks, which can have very high energy use per tonne-kilometer—although perhaps it would be more helpful to measure the goods movements in value rather than weight.

Rail freight often is viewed as a very energy-efficient way of moving goods. Average rail-freight primary energy intensities, at around 0.7–1 MJ/tonne-km, are a quarter of those of average road-freight intensities (CEC, 1992; Schipper *et al*., 1993; Tanja *et al*., 1992). However, it is important to compare similar types of goods movements. The energy intensity of rail container freight, at 0.4–0.9 MJ/tonne-km, may not be much smaller than that of road container freight, at 0.7–1.0 MJ/tonne-km (Martin and Shock, 1989; Rigaud, 1989; CEC, 1992).

Marine transport, on average, is the most efficient means of bulk international goods movement, with energy intensities below 0.2 MJ/tonne-km (Bremnes, 1990). Dry bulk goods (e.g., iron ore, cereals, coal, bauxite, and phosphate rock), crude oil, and oil products make up 60 to 70% of goods movements by sea and are moved in the largest, most efficient vessels. There has been a strong trend toward larger vessels (up to 170,000-tonne capacity) to capture economies of scale in both investment and operating costs of ships (Doyle, 1986).

21.3. Reducing Transport Greenhouse Gas Emissions

Greenhouse gas emissions from the transport sector and its energy supply chain can be reduced by policies and measures aimed at:

- Reducing energy intensity through vehicle downsizing, lower power-to-weight ratios, more efficient vehicle technology, changes in vehicle use (load factor, driving style, traffic management, etc.), improvements in infrastructure, or changes in transport mode
- Controlling emissions of carbon monoxide, VOCs, NO_x, N_2O, and methane
- Switching to alternative energy sources with lower full-fuel-cycle greenhouse gas emissions
- Reducing the use of motorized vehicles through switches to nonmotorized transport modes, substitution of transport services with other services (e.g., telecommunications), or reduction in the services consumed.

Section 21.3 provides a review of the potential for technical change to reduce transport greenhouse gas emissions. Section 21.4 addresses the role of policy in changing technology and its use.

21.3.1. The Technical and Economic Potential for Vehicle Changes

Studies of the potential for technical change can give a huge range of results even for a single technology in a single country. For example, in the United States, estimates of potential new-car fuel economy for the late 1990s range from 4.8 to 8.4 L/100 km (DeCicco and Ross, 1993; NRC, 1992; OTA, 1991). Analyses differ partly in the assumptions made but also in the type of potential being considered. It is helpful to distinguish among the *technical potential* (the reduction in greenhouse gas emissions that would result from application of the best available technology), the *economic potential* (the reduction in emissions that can be achieved cost-effectively), and the *"policy" potential* (the reduction in emissions that can reasonably be achieved as a result of policies and measures).

The technical potential usually improves with time as new fuels, prime movers, materials, design techniques, and operating systems become available. The economic and policy potentials do not necessarily improve; they depend on the economic and other priorities of the providers and users of transport services. The extent to which these potentials are achieved depends on a complex interaction among technology, the economy, and choices made by consumers, producers, and policymakers. It is this interaction that most needs to be understood and addressed if policymakers wish to reduce greenhouse gas emissions from the transport sector.

21.3.1.1. Energy-Intensity Potential in Road Vehicles

Reductions in energy use per vehicle-kilometer can be achieved through changes in maintenance practice, vehicle-body design changes, more energy-efficient engine and drive-train designs, and changes in operating practice.

Vehicle maintenance may be inadequate because spare parts and servicing are too expensive or unavailable (Davidson, 1992) or because maintenance is a low priority for drivers. Regular checks on tire pressure, engine oil, and tuning can save energy. Studies on cars have shown a 2 to 10% fuel saving immediately after engine tuning (Davidson, 1992; Martin and Shock, 1989; Pischinger and Hausberger, 1993). Some countries—including Mexico, Korea, and some European countries—and some American states have introduced regular vehicle emission tests, with remedial action when necessary, usually including engine tuning.

Vehicle mass affects energy use for acceleration and in overcoming resistance or friction in the axles, wheels, and tires. In most types of road vehicle, acceleration and rolling resistance each typically account for around a quarter to a third of the useful mechanical energy from the engine, although these shares are larger for city buses and delivery vans. Vehicle mass can be reduced by using advanced materials, improving component design and joining techniques, and reducing vehicle size or engine size. Concept cars have been demonstrated with masses 30 to 40% below those of conventional cars of similar size and performance (Chinaglia, 1991; Delsey, 1991b; Lovins *et al*., 1993). The technical potential in 2010 for mass reductions without compromising comfort, safety, and performance is probably in the range of 30 to 50% for most vehicle types; this is the target of the United States' Partnership for a New Generation of Vehicles (PNGV). Such a mass decrease would lead to reductions in energy intensity in the region of 15 to 30%, provided engine size is reduced to keep performance constant (ETSU, 1994).

The technical potential in 2010 for reducing *rolling resistance* is probably around 30% for cars but rather less in buses and trucks (ETSU, 1994; DeCicco and Ross, 1993). For most road-vehicle types, a 10% drop in rolling resistance reduces energy intensity by roughly 2 to 3%, provided engine size is reduced (ETSU, 1994).

Air resistance, or drag, accounts for a third to a half of the energy required to move most types of vehicles, although the share is lower for city buses and delivery vans. Changes in vehicle design can reduce it by about 50% for most vehicle types without sacrificing performance—offering a 15 to 30% reduction in energy intensity, provided engine size is reduced (ETSU, 1994). The ultimate limit on drag reduction without reducing vehicle size is probably 70 to 80%, but this would involve radical changes in vehicle shape and performance.

Improved *transmission designs* can reduce energy use by allowing the engine to operate closer to its optimum speed and load conditions. Complete engine load/speed optimization can be achieved with electronically controlled continuously variable transmissions (CVT), although these may be more expensive than conventional gearboxes and currently are available only for small cars. Energy savings in the range of 3 to 10% are possible relative to automatic transmissions (DeCicco and Ross, 1993; Tanja *et al*., 1992; NRC, 1992).

The three-way *catalytic converter*, combined with electronically controlled fuel injection into the engine air-intake manifold, is rapidly becoming standard for new gasoline cars in medium- and upper-income countries. This technology reduces emissions of carbon monoxide, unburned hydrocarbons, and NO_x from gasoline cars by approximately 60 to 90% relative to a car with a carburetor and no catalytic converter. N_2O emissions are raised approximately fivefold but depend strongly on the age of the catalyst and driving pattern (Ybema and Okken, 1993). The overall effect on radiative forcing of adding a catalytic converter to a gasoline car is small and uncertain; there may be a reduction in some circumstances (CEC, 1992; Pischinger and Hausberger, 1993; Wade *et al*., 1994).

In *heavy-duty diesel engines*, the main needs for exhaust-gas pollution control relate to particulate and NO_x emissions. Controls such as particulate traps and filters tend to reduce energy efficiency and increase CO_2 emissions, without any compensatory effect from reductions in other greenhouse gases. However, other approaches to reducing engine emissions, such as the use of electronic fuel-injection systems, can lead to reductions in both engine pollution emissions and fuel consumption.

Changes in *gasoline-engine technology* have resulted in gradual improvements in energy efficiency. This progress is likely to continue. Energy-intensity reductions in the range of 15 to 30% are thought to be available with current technology (Bleviss, 1988; CEC, 1992; DeCicco and Ross, 1993; ETSU, 1994; NRC, 1992; Pischinger and Hausberger, 1993). These reductions could arise from a combination of many changes, including improvements in component design and lubrication, improvements in materials, increased use of electronic control systems, and changes in engine design such as the use of three or four valves per cylinder.

Car manufacturers have worked intensively on advanced two-stroke engines with the aim of reaching the noise, emission, and durability standards of existing four-stroke engines. The two-stroke engines would have higher efficiency and power-to-volume and weight ratios than four-stroke engines, allowing for more flexibility in car design and potentially for improvements in fuel economy of around 10%, provided the efficiencies realized were not used to raise power.

Another engine concept is the gasoline direct-injection engine, which might have fuel requirements 10 to 25% lower than those for a conventional engine (Schäpertons *et al*., 1991); such engines remain far from commercialization however. Lean-burn gasoline engines also may offer 10 to 20% energy savings, but further development will be needed in the engines, or in the development of a lean-burn engine NO_x reduction catalyst, to meet future NO_x emission standards.

Diesel engines in heavy-duty vehicles are already very efficient. The energy efficiency of a large truck engine can approach 40% in use. The potential for further energy savings is probably no more than 10 to 20% in the long term.

Diesel-engine cars, taxis, and vans are widespread in Europe, the Middle East, and Southeast Asia, although they cannot meet some strict U.S. emission standards. Most of these cars have indirect-injection diesel engines and offer 5 to 15% lower fuel consumption (in energy terms) than gasoline cars. Cars with direct-injection diesel engines consume about 10 to 20% less fuel than indirect-injection diesel engines.

Alternative engine designs, including gas turbines and Stirling engines, have received attention from governments and manufacturers over the decades. These engines are cleaner than Otto or diesel engines and are also fuel-flexible, but in the 50 to 300 kW range required for road vehicles, they are currently inefficient and expensive and have poor load-following characteristics. By 2025, improved materials and precision engineering could make these engine types viable for road vehicles. Hybrid engine/electric drivetrains could be used to avoid the need for the engine to match the load on the drivetrain. These are discussed in Section 21.4.

21.3.1.2. Cost of Energy-Intensity Improvements

Several studies (DeCicco and Ross, 1993; Greene and Duleep, 1993; NRC, 1992) use cost models to estimate the potential for reducing the energy intensity of car use in the United States. However, as DeCicco and Ross (1993) observe, it is hard to predict which technical changes will raise manufacturing costs and which will lower them. Changes in materials and manufacturing technique, in particular, frequently result in reduced costs. It is also difficult to carry out cost-effectiveness analysis on changes in vehicle design because many changes have some effect on the appearance if not the performance of a vehicle, and this can influence purchasers' willingness to pay for the changes.

21.3.1.3. Energy-Intensity Potential for Aircraft

Balashov and Smith (1992) estimate that fuel intensity in scheduled air passenger services will improve at an average of 3% per year during the 1990s and 2.5% per year from 2000 to 2010. With traffic expected to grow at 5.5% per year in the 1990s and 5% per year from 2000 to 2010, total fuel consumption could be about 65% higher in 2010 than in 1990. Beyond 2010, fuel-intensity improvements would have to come from the introduction of new engine concepts. An example might be the use of lightweight heat exchangers to provide charge cooling and recuperate exhaust heat from the engine. If such technologies could be applied in aviation, they might, in theory, provide a 20 to 25% energy savings (Grieb and Simon, 1990).

If a new generation of supersonic aircraft is successfully developed and commercialized, it would likely lead to an increase in the average energy intensity of civil air traffic and possibly an increase in traffic.

21.3.1.4. Energy-Intensity Potential for Ships

The energy efficiency of existing ship engines can approach 50%, and only small improvements (5 to 10% savings in fuel used) are anticipated in the future. Hull and propeller design improvements could reduce energy use by a further 10 to 30% (CEC, 1992).

Some existing ships use sails to assist their engines, and one option that has been claimed to save 10 to 20% of ship energy is the use of wind assistance by means of vertical-axis wind turbines (CEC, 1992). These have the added advantage of improving ship stability.

21.3.1.5. Summary of the Potential for Vehicle Energy-Intensity Improvements

By 2010, it may be technically possible to reduce energy intensities for new vehicles of most types by 25 to 50% without

Table 21-5. *Potential for energy efficiency.*[a]

Mode	National Average Load Factors (pass. per seat or tonne load per tonne capacity)[b,d]	National Averages of 1990 Intensity (MJ/pass-km or MJ/tonne-km)[d]	Trend[c,e]	Economic Reduction Potential at Constant Performance[c,e]	Technical Reduction Potential at Constant Performance[c,e]	Technical Reduction Potential: Reduced Speed and Performance[c,e]
			-------- Percentage Change Relative to 1990 Intensity ----------			
Cars	0.25–0.5	1.2–3.1	0 to -30	-20 to -50	-35 to -70	-60 to -80
Buses	0.1–2	0.2–1.3	+10 to -10	0 to -20	-20 to -40	-35 to -60
Trams	0.2–0.8	0.3–1.5	+10 to -10	0 to -20	-20 to -30	-30 to -40
Passenger Trains	0.1–0.8	0.9–2.8	+10 to -10	0 to -20	-25 to -35	-35 to -45
Air Travel	0.5–0.8	1.5–2.5	-10 to -20	-20 to -30	-30 to -50	-40 to -60
Avg. Road Freight	0.2–0.4	1.8–4.5	-10 to -20	-15 to -30	-25 to -50	-40 to -70
Heavy Trucks	0.6–1.1	0.6–1.0	0 to -20	-10 to -20	-20 to -40	-30 to -60
Freight Trains	0.5–0.8	0.4–1.0	0 to -10	-10 to -20	-25 to -35	-30 to -40
Marine Freight	–	0.1–0.4	+10 to -10	+10 to -10	-20 to -30	-30 to -50
Air Freight	n/a	7–15	-10 to -20	-20 to -30	-30 to -50	-40 to -60

[a] Actual potentials depend strongly on vehicle load factors and patterns of use.
[b] Load factors exceeding 1.0 indicate overloading.
[c] 2010 new stock, 2025 fleet average.
[d] Bose and MacKenzie, 1993; CEC, 1992; Davidson, 1992; Hidaka, 1993; Rigaud, 1989; Schipper *et al*., 1993; UNESCAP, 1989 to 1992, various.
[e] Much of the literature on trends and potentials is focused on cars from 2000 to 2005 (e.g., Difiglio *et al*., 1990; Greene and Duleep, 1993; DeCicco and Ross, 1993; IEA, 1993a). Values here are the authors' estimates, revised following expert review, based on these and on longer term estimates covering various transport modes in Bleviss (1988), CEC (1992), ETSU (1994), Lovins (1993), Martin and Shock (1989), Pischinger and Hausberger (1993), and Walsh (1993a).

reducing vehicle performance or the quality of transport provided (see Table 21-5). However, the economic potential—the energy-intensity reduction that would be cost-effective—is likely to be smaller than the technical potential. As Table 21-5 indicates, the economic potential for energy savings in cars might be about two-thirds the technical potential. Meanwhile, the trend is for less energy saving than the economic potential; for some key vehicle types, including cars and heavy trucks, it is possible that the fleet average energy intensity might not decrease between 1990 and 2025. Substantial reductions in energy intensity would require new government measures and might entail reductions in vehicle performance.

If the vehicle energy-intensity trends in Table 21-5 are combined with road traffic projections from Walsh (1993b) and air traffic trends from Balashov and Smith (1992) extrapolated to 2025, energy use in the transport sector in 2025 could be 90–140 EJ. This assumes no significant changes in energy use by rail and marine transport. The adoption of energy-efficiency improvements—to achieve the technical potential in energy use at constant performance—would result in energy use in 2025 reduced by around a third to 60–100 EJ.

21.3.1.6. Life-Cycle Greenhouse Gas Emissions

Land-based transport. Several analysts have estimated greenhouse gas emissions from road vehicles on a life-cycle basis that includes vehicle manufacture, vehicle operation, and fuel supply (CEC, 1992; DeLuchi, 1991, 1993b; IEA, 1993a; Pischinger and Hausberger, 1993). CEC (1992) also includes estimates of emissions associated with vehicle disposal and addresses emissions from trains, shipping, and aircraft. All of these sources estimate emissions of CO_2, CO, VOCs, CH_4, NO_x, N_2O, and CFCs, converted to CO_2-equivalents with a variety of GWP estimates. These GWPs all have been superseded by more recent values. Chapter 2.5, *Trace Gas Radiative Forcing Indices* in IPCC Working Group I volume, estimates GWPs as follows for a 100-year time horizon: CH_4, 24.5; N_2O, 320; CFC-12, 8500; HFC-134a, 1300. These values have been used by the authors to recalculate the life-cycle greenhouse gas emissions from various transport modes. GWPs for NO_x, VOCs, and CO are not estimated but are all expected to be greater than zero (Chapter 2.5, *Trace Gas Radiative Forcing Indices* in IPCC Working Group I volume).

The principal greenhouse gas emissions in a vehicle life cycle are CO_2 in the vehicle exhaust, during vehicle manufacture, and in the process of fuel supply; CFCs, primarily as a result of leakage from air conditioning and refrigeration systems; CH_4 emitted during oil extraction and from vehicle disposal where organic wastes are placed in landfills; and N_2O produced during fuel combustion and in the catalytic converters currently used for gasoline engines in many countries.

Vehicles are the main source in some countries of CO, NO_x, and unburned hydrocarbons. Although these are precursors of ozone—and hence are indirect greenhouse gases, GWPs cannot be reliably estimated for them (Chapter 2.5, *Trace Gas Radiative Forcing Indices* in IPCC Working Group I volume). The increasing use of catalytic converters on gasoline-engine cars during the coming 10 to 20 years will reduce emissions of ozone-forming gases and increase emissions of N_2O. The overall greenhouse-forcing impact of this change is likely to be small or neutral.

Air conditioning is likely to be installed in an increasing proportion of cars, although HFC-134a is likely to be used as the main refrigerant instead of CFC-12. At current rates of refrigerant loss, HFC-134a would add about 10% to the life-cycle greenhouse forcing caused by a passenger car. Improved equipment design and maintenance could reduce this loss, perhaps to near zero.

Car air-conditioning systems are powered by electricity generated from the engine alternator at very low efficiency. When operating, they add to vehicle fuel consumption, further increasing greenhouse gas emissions.

For diesel or electric-powered vehicles, emissions of non-CO_2 greenhouse gases contribute a smaller proportion of overall emissions than they do for gasoline cars. Buses, trucks, and trains have much higher utilization rates (distance traveled per year and in their lifetimes), so emissions associated with operation (tailpipe and fuel-supply emissions) dominate life-cycle emissions (CEC, 1992).

Aircraft. Besides CO_2, emissions of NO_x at high altitudes may make a similar contribution to climate change. While CO_2 is emitted in proportion to fuel consumption, factors influencing NO_x emissions from aircraft engines are more complex, and there may be some tradeoff between NO_x emissions and engine efficiency. During the past decade, manufacturers have developed several approaches to reducing aircraft engine NO_x emissions without compromising energy efficiency. New, more complex combustion systems are currently being developed that are anticipated to provide a 30 to 40% reduction of NO_x emissions. These targets appear to have been achieved by one medium-size engine that entered service in 1995, but not by a larger model, owing to major materials and cooling limitations. For the latter, the potential and time scale for achieving the anticipated 30 to 40% reduction are open to question. Research also is underway—primarily aimed at a second generation of supersonic civil aircraft—on systems to achieve greater than 80% reductions. Such systems could start entering service between 2005 and 2010 (Grieb and Simon, 1990).

21.3.2. Operational Influences on Vehicle Greenhouse Gas Emissions

The energy intensity of travel and freight transport is influenced by several factors other than vehicle technology. One of the single strongest influences is the load factor or occupancy of the vehicle, but other factors—including driving style (or speed profile), routing, and traffic conditions—also are important.

Differences in driving style can explain about 20% of variations in energy use by cars, buses, and delivery vans in urban areas (Martin and Shock, 1989; Tanja *et al*., 1992). The potential for energy saving by "gentler driving" has been estimated to be about 10% in urban areas and 5 to 7% overall (Tanja *et al*., 1992).

Energy use also can be reduced by traffic-management measures, such as computerized traffic-light control and network and junction design, to reduce congestion and unnecessary stops. Introduction of a traffic-control system in Los Angeles is estimated to have yielded a 12.5% reduction in energy use (Shaldover, 1993). However, energy-use reductions resulting from computerized traffic control may be rapidly reversed because the increase in road network capacity is likely to produce additional traffic.

For commercial vehicles, computerized routing systems can be used to optimize payloads and minimize the time spent and fuel used on the roads. For many haulage firms in industrialized countries, such systems pay for themselves through increased revenue. Some studies indicate that reductions of 25 to 30% in energy use per tonne-kilometer are technically possible (O'Rourke and Lawrence, 1995).

A variety of computerized routing aids are being developed for drivers in general, some providing real-time information on congestion and the availability of alternative modes and routes. Energy-saving potentials in urban road passenger transport could range from a few percent in small towns with little congestion to 30% in large, congested conurbations with effective public-transport alternatives (Shaldover, 1993).

For aircraft, while present flight patterns seek to minimize costs—particularly fuel consumption—there might be scope for operational changes, including alternative routings to avoid greenhouse gas precursor emissions at sensitive altitudes (such as the tropopause), latitudes, and longitudes, or changing seasonal or diurnal patterns that might reduce the impact on atmospheric processes. Civil airlines operate increasingly sophisticated computerized booking systems with multiple tariffs, and the resultant increase in seat occupancy has contributed to falling energy intensity. Further increases in occupancy are likely (Balashov and Smith, 1992).

Speed is an important influence on energy use by all types of vehicles. For road and rail transport, speed limits and vehicle speed limiters are mainly used for safety reasons. Moderate reductions in average road vehicle speed (e.g., from 90 km/h to 85 km/h) can lead to energy savings on the order of 5 to 10% (Tanja *et al*., 1992). In ships and aircraft, speed is routinely controlled to manage energy costs. Because fuel constitutes 20 to 30% of shipping costs, operators plan voyages using shipping cost models that take account of energy use in choosing the optimum speed. An oil price of $30/barrel can produce optimum speeds 25% lower than a price of $15/barrel; the result is a 33 to 40% energy saving (Doyle, 1986).

21.3.3. Alternative Fuels

Alternative fuels are an important complement to measures that improve fuel economy as a means of reducing greenhouse gas emissions. In the past, alternative-fuel vehicles (AFVs) have been developed as a means of reducing oil consumption; they currently are being promoted as a means of reducing urban air pollution. Some types of AFVs can contribute to meeting both of these goals.

21.3.3.1. Alternative Fuels in Light-Duty Vehicles

For gaseous fuels and alcohols, engine emissions of carbon monoxide are generally lower than with gasoline, and particulate emissions are much lower. Engine NO_x emissions are generally similar to or lower than those from conventional fuels (Gover *et al*., 1993; IEA, 1993a; OECD, 1993c; Wang, 1995). Emissions of unburned fuel and certain other pollutants, such as formaldehyde, on the other hand, can be higher than for gasoline or diesel fuel. In the short term, some of the main applications for alternative fuels are likely to be in situations where they can substitute for conventional gasoline additives, such as methyl tertiary butyl ether (MTBE), in helping to meet reformulated gasoline requirements (IEA, 1994b).

On a full fuel-cycle basis, alternative fuels from renewable energy sources have the potential to reduce greenhouse gas emissions from vehicle operation (i.e., excluding those from vehicle manufacture) by 80% or more (CEC, 1992; DeLuchi, 1991; IEA, 1993a).

Estimated life-cycle greenhouse gas emission ranges for several fuels, based on a variety of sources, are shown in Table 21-6, which also shows cost estimates for using some of the alternative-fuel vehicles. Some of the fuels listed are already cost-competitive with gasoline in some circumstances. These include diesel, liquefied petroleum gases (LPG), and compressed natural gas (CNG), all of which are in current use. Vehicles operating on these fuels may have full fuel-cycle greenhouse gas emissions about 10 to 30% lower than vehicles operating on gasoline, as shown in Table 21-6. These alternative fuels are used preferentially in high-mileage vehicles, where low fuel costs compensate for high engine and fuel-storage costs. Methanol from natural gas also may be cheaper to use than gasoline in some circumstances and might offer slight greenhouse gas-emission reductions. Methanol from coal also could be cost-competitive with gasoline, but with a 10 to 75% increase in greenhouse gas emissions (DeLuchi, 1991).

Alcohol fuels can be produced in a variety of ways from any of several sources. Life-cycle greenhouse gas emissions depend on the source and conversion technology (DeLuchi, 1993; IEA, 1993a), as Table 21-6 shows. Ethanol is produced from sugar cane for transport use in several countries, including Brazil, Zimbabwe, and Kenya. Full fuel-cycle greenhouse gas emissions are estimated to range from 30 to 50% of those that would be obtained with gasoline where bagasse (crop waste) is used as fuel for conversion facilities to around 80 to 90% where coal is used (estimates based on Goldemberg and Macedo, 1994; IEA, 1994b; Rosenschein and Hall, 1991). N_2O emissions from agriculture form a substantial but uncertain component of these estimates.

Ethanol is produced from corn on a large scale in the United States, where it provides about 0.5% of gasoline demand in energy terms. It is produced from wheat and sugarbeet on a small scale in Europe. Cars using ethanol produced from these food crops would have life-cycle greenhouse gas emissions ranging from 20% of those from gasoline cars when crop waste is used as the conversion fuel (not the current practice anywhere) to nearly 110% where coal is used (Table 21-6; IEA, 1994b).

Hydrogen can be used either in internal combustion engines or in fuel cells. Where hydrogen is produced from renewable sources—either by gasification of biomass or by electrolysis of

Table 21-6: *Life-cycle greenhouse gas emissions and costs for alternative fuel and electric cars (based on DeLuchi, 1992, 1991; IEA, 1993a[a]; CEC, 1992; Pischinger and Hausberger, 1993; Goldemberg and Macedo, 1994; DOE, 1991, 1990, 1989).*

	Greenhouse Gas Emissions in g/km CO_2-equivalent[b]				**Pre-Tax Costs[c]**			
Fuel	Vehicle Manufacture[d]	Fuel Supply[e]	Operation[f]	Total	Vehicle Cost ($)	Fuel Cost ($/L gasoline equiv.)	Fuel Use for Cost Calculation (L/100 km)	Cost in Excess of Gas Vehicle @29US¢/km (US¢/km)
Gasoline	25–27	15–48	182–207	222–282	15168	0.26	7.6	0
Reformulated Gasoline	25–27	17–63	180–193	222–283	15168	0.28–0.30	7.6	0.18–0.32
Diesel	27–29	7–35	139–202	173–266	15168–17443	0.26	6.08	-0.35–3.64
Liquefied Petroleum Gases	26–28	7–20	147–155	180–203	16083–15384	0.19–0.26	7.27	-0.55–1.02
Compressed Natural Gas	29–31	5–68	130–154	164–253	16083–15600	0.18–0.24	7.27	-0.28–0.90
Methanol from Coal	25–27	250	149	424–426	16128–15168	0.25–0.35	7	-0.72–1.45
Methanol from NG	25–27	76	149	250–252	16128–15168	0.25–0.35	7	-0.72–1.45
Methanol from Wood	25–27	25–38	15–16	65–81	16128–15168	0.68–0.82	7	2.30–4.79
Ethanol from Sugar Cane	25–27	30–80	15–16	70–123	16128–15168	0.35–0.38	7	-0.17–1.89
Ethanol from Corn	25–27	50–220	15–16	90–263	16128–15168	0.94–1.03	7	4.61–6.74
Ethanol from Wood	25–27	25–38	15–16	65–81	16128–15168	0.68–0.82	7	2.79–5.27
Liquid Hydrogen ICEV	26–28	0–48	3–12	29–88	19968–18048	0.38–1.44	6.5	4.10–13.97
Liquid Hydrogen FCEV	44–48	0–24	0–5	48–77	20324–30000	0.38–1.44	3.25	6.22–25.64
EV using Electricity Generated from:[g]								
American Average	44–48	135–202	0	179–250				
European Average	44–48	107–160	0	151–208	24768–20928	0.48–0.96	2–3	6.81–14.74
Coal	44–48	180–375	0	224–423				
Oil	44–48	170–255	0	214–303				
Gas (CCGT)	44–48	90–134	0	134–182				
Nuclear	44–48	15	0	59–63				
Hydro/Renewables	44–48[h]	0	0	44–48				

[a] Both the work of the IEA and that of Pischinger are based on a model developed by DeLucchi (1991, 1993).
[b] Average driving cycle based on gasoline car consuming 7 L/100 km; GWPs are for 100-year time horizon (CH_4, 26; N_2O, 270; CO, 3; VOC, 11; NO_x, 0). These differ from the latest IPCC values (IPCC, 1995), but the effect on total life-cycle emissions estimates is negligible.
[c] Based on Renault Clio 1.4 liter, 13800 km/year, 10-year life, 10% d.r.; levelized cost calculations based on IEA, 1993.
[d] Assumes current industrial practices. Ranges reflect differences between regions.
[e] Ranges reflect differences between primary energy sources and conversion technologies.
[f] Ranges reflect differences in vehicle technology, maintenance, and operation.
[g] Emissions based on urban cycle, consuming 200–300 Wh/km from mains (IEA, 1993a; CEC, 1992; DeLucchi, 1993; Eyre and Michaelis, 1991).
[h] DeLucchi (1991) and IEA (1993) ignore emissions associated with electricity-generating plant and electricity-grid construction. In fact, some CO_2 emissions will occur during plant construction, both from energy use and from cement manufacture. Emissions also may result from the flooding of land for hydroelectricity production.

Box 21-1. Ethanol in Brazil

Brazil has used small amounts of ethanol for decades as an octane enhancer in gasoline and as a byproduct market for the sugar industry. However, in the late 1970s, rising oil prices combined with high interest rates and a crash in the world sugar market to create a foreign-debt-servicing crisis. This compelled the Brazilian government to look at ways of reducing petroleum imports.

From 1975 to 1979, the government-sponsored program, Proalcool, increased the ethanol percentage in gasohol to 20%. From 1979 to 1985, Proalcool promoted the use of dedicated ethanol vehicles. In 1986, ethanol vehicles constituted 90% of new car sales, but a further expansion of the program was mothballed because of the drop in the price of oil. In the first phase of the program, the government provided up to 75% subsidies for ethanol-producer investments and assured a 6% return on the investments. At this stage, however, car manufacturers were unwilling to produce ethanol-only vehicles. In the second phase, consumer incentives were introduced for vehicle purchases, and the pump price of ethanol was guaranteed to be no more than 65% that of gasoline. The car industry was encouraged by the government's commitment and started producing ethanol vehicles. Despite initially poor redesign of engines, the consumer take-up was massive.

In late 1980, the world sugar market was improving, and the government began to increase the ethanol price from 40% of the of gasoline price toward the 65% limit. Credit subsidies for distilleries also were suspended. The result was a rapid fall in ethanol-vehicle purchases. The government later regained public confidence by restoring incentives.

Costs of ethanol production in Brazil are around 25 to 28¢/L of gasoline displaced, compared with world market prices of gasoline on the order of 17¢/L (pump costs are usually about 10¢/L higher). The government's current limit on the pump price of ethanol is 80% of the gasoline price.

Sources: Sathaye *et al*. (1989); Goldemberg and Macedo (1994).

water with electricity from renewables—life-cycle greenhouse gas emissions can be very low. The method of hydrogen storage aboard the vehicle can affect life-cycle emissions. If hydrogen is liquefied for storage, the energy input is about one-third of the energy content of the hydrogen; emissions, of course, will depend on how this energy is supplied (DeLuchi, 1993; ETSU, 1994).

Several trials have been carried out, with varying success, of hydrogen cars with Otto-cycle engines. Fuel consumption could, in theory, be 15 to 20% lower than that of gasoline engines on an energy basis (Brandberg *et al*., 1992; DeLuchi, 1991; ETSU, 1994). Considerable technical development will be required in the various stages of hydrogen production, distribution, storage, and use before it is economical to use in cars and its safety can be fully demonstrated.

21.3.3.2. Alternative Fuels in Heavy-Duty Vehicles

Buses have been operated on LPG, CNG, alcohols, and vegetable oils, and there are several demonstration programs and commercial operations throughout the world. Fewer studies have been carried out into life-cycle greenhouse gas emissions from heavy-duty vehicles than from cars. However, Figure 21-7 shows results from one study (DeLuchi, 1993; IEA, 1993a). This study shows that most of the immediately available alternative fuels for heavy-duty vehicles are unlikely to offer life-cycle greenhouse gas emission reductions. The main reason for this conclusion is that CNG and LPG are used in spark-ignition engines with lower efficiency than existing diesel engines. Alcohols can be used in compression-ignition engines, but expensive fuel additives are required, and spark ignition engines usually are preferred.

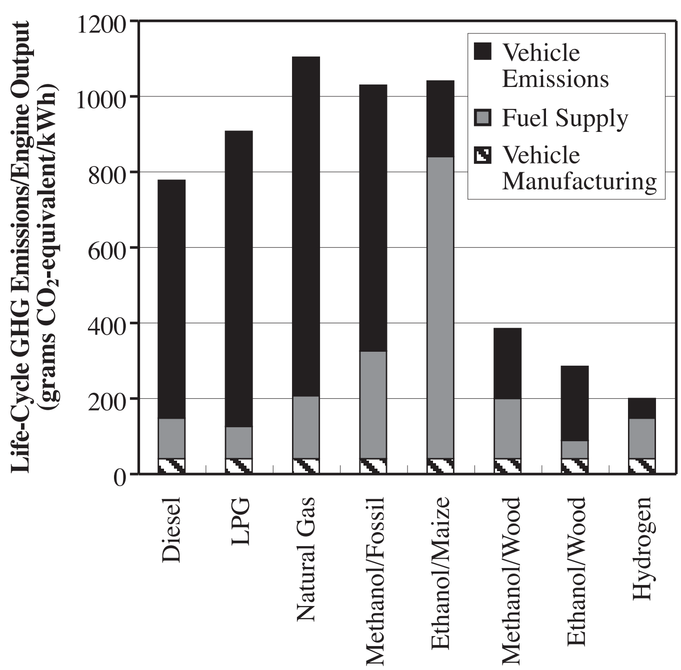

Figure 21-7: Life-cycle greenhouse gas emissions from heavy-duty vehicles with alternative fuels (DeLuchi, 1993; IEA, 1993a).

Box 21-2. CNG in New Zealand

The New Zealand government launched a compressed natural gas (CNG) program in 1979, aiming for 150,000 post-assembly vehicle conversions to CNG by the end of 1985. The main motivations for the program were to enhance New Zealand's energy security and improve its balance of payments. Incentives were provided in the form of grants and loans for vehicle conversion and filling-station development. The cost of car conversion at the time was about NZ$1,500 (US$750 in 1984 prices); the government provided NZ$150. Initial take-up was poor, but it was improved in late 1980 by an increase in the grant to NZ$200 and increased subsidies to fueling stations, along with tax benefits to consumers.

A large increase in government support in 1983 included a low-interest loan for conversions. By 1986, 110,000 vehicles (11% of all cars and light trucks) had been converted, and New Zealand had 400 filling stations; CNG comprised 4.6% of road-transport fuel.

The rise in conversion rate was halted in 1985 when the government reduced support for the program because of perceptions that CNG was sufficiently favored by its low price relative to gasoline, the CNG industry was sufficiently well-established and no longer required government support, and world oil markets were more stable and less emphasis was needed on the development of indigenous energy sources.

The vehicle conversion rate fell from 2,400/month in 1984 to 150/month by 1987. By 1993, CNG sales fell to 42% of their peak level in 1985, contributing only 2% of road-transport fuel. In addition to the withdrawal of government subsidies to CNG, a number of factors may have contributed to this demise. One is the increase in CNG prices from less than half to about two-thirds of the gasoline price, at a time when oil markets have been quite stable. Another possible factor is a negative public perception of CNG resulting from a number of faulty installations in the early 1980s, a cylinder explosion in 1989, the poor performance of dual-fuel vehicles that were not optimized to operate on CNG, and the realization that carrying CNG cylinders substantially reduces luggage space. A third possible factor is a lack of industry enthusiasm for marketing the fuel, bearing in mind that most of the retail outlets are oil-company-owned filling stations.

Sources: Sathaye *et al*. (1989); New Zealand Ministry of Commerce (1994).

In the long term, alternative fuels, such as methanol and ethanol from wood, could be used in heavy-duty vehicles, producing life-cycle emission reductions of more than 50% relative to diesel vehicles. Meanwhile, developments in direct-injection, compression, or spark-ignition engines operating on CNG, LPG, and alcohols could lead to substantial improvements in efficiency with these fuels (CEC, 1992).

Another option not shown on Figure 21-7 is the use of synthetic diesel produced from renewable sources, such as wood. This strategy would allow existing, efficient diesel engine technology to be used with a fuel with very low full-fuel-cycle carbon emissions.

21.3.3.3. Alternative Aviation Fuels

Aircraft carry a large amount of fuel in proportion to their total weight (around half of the takeoff weight for a Boeing 747). In view of this, any alternative fuel has to have a high energy content per unit of mass. LNG and liquid hydrogen fit this requirement, and trials have been carried out with both (Grieb and Simon, 1990; Schäfer *et al*., 1992). In principle, both LNG and liquid hydrogen aircraft could have lower fuel consumption than conventional aircraft because of the lower weight per unit of energy in the fuel. Energy use depends on the additional weight of the fuel tanks, the design changes required in the aircraft, and the energy required to liquefy the fuel. Overall greenhouse gas emissions from the use of these fuels, including emissions of NO_x and water vapor, cannot yet be predicted. The implications for climate change depend on the GWPs of high-level NO_x and high-level water vapor, which remain uncertain—as do the safety implications of using cryogenic methane and hydrogen in aircraft.

If low-carbon fuels are required for aviation, a safer alternative might be synthetic liquid hydrocarbons from biomass, although even these fuels may have drawbacks, such as poor thermal stability. It will be necessary to demonstrate the safety and reliability of aircraft engines that use synthetic hydrocarbons before they can be adopted for civil aviation purposes.

21.3.4. Electrically Powered Transport Systems

Many analysts believe that the most promising route for the development of transport systems, along with the rest of the energy economy, would be toward the use of either electricity or hydrogen as energy carriers (MacKenzie, 1994; Sperling *et al*., 1992; Sperling, 1995). This strategy would effectively make final energy use independent of the primary source of energy, allowing renewables such as photovoltaics, wind power, and biomass to be used interchangeably as the electricity or hydrogen source.

Emissions can be eliminated at the point of vehicle operation by the use of some form of electric drive. Power can then be supplied by oxidation of hydrogen in a fuel cell, from an electrical storage device, or directly from the public electricity supply. Electric motors have the advantage of high efficiency at part-load, no fuel consumption when stationary, and the potential for regenerative braking (where the motor is used as a generator to return power to the source or a storage device).

Battery electric vehicles have aroused interest mainly for their potential to reduce urban air pollution. Electric-vehicle technology has been reviewed in detail by several authors (CEC, 1992; DeLuchi, 1991, 1993; ETSU, 1994; IEA, 1993b; MacKenzie, 1994; Sperling, 1995). Life-cycle greenhouse gas emissions depend not only on the primary energy source but also on many aspects of the vehicle technology and the way it is used.

Electric-car technology has been intensively developed in several countries in recent years, mainly as a result of legislation in California. Batteries have so far provided the best combination of energy and power density, along with low cost for on-vehicle electricity storage. Battery-powered cars, buses, and light vans are in use, but they have high costs and poor performance compared with gasoline vehicles, and most types of battery would need replacing several times in the life of a vehicle. The future evolution of this technology and of the market for electric vehicles is very uncertain, depending on factors such as the extent of cost reductions that can be achieved in batteries, electric motors, and control systems; the extent to which battery-recharging rates, energy densities, and power densities can be improved; and market factors, including consumer preference and future legislation to reduce air pollution.

Alternatives to the battery are under development. Whereas batteries store energy in the form of chemicals that react to produce electric power, supercapacitors store energy in the form of electric charge, and flywheel storage devices store energy in the kinetic energy of a rapidly rotating flywheel. These devices may have the potential for much higher power density than batteries, with similar energy-storage density.

Some recent studies in California (Bunch *et al.*, 1993) indicate that, in choosing between conventional and alternative vehicles, car purchasers are likely to be particularly sensitive to the extra cost and shorter range of battery-powered and other alternative-fuel vehicles. Other studies in California (Sperling, 1995) have found that consumer preferences can be modified and that a substantial proportion of drivers might purchase electric vehicles to use for local trips and commuting, keeping their gasoline vehicles for other trips.

The range and durability limitations of batteries are avoided with fuel cells, which produce electric power directly from the oxidation of a fuel carried in a separate storage vessel. The fuel normally is hydrogen, although some fuel-cell types can use methanol or other fuels. Alternatively, methanol can be used to make hydrogen on board the vehicle. Of the various fuel-cell types, the solid polymer fuel cell (SPFC) is probably the strongest near-term candidate for an on-vehicle power source (Appleby and Foulkes, 1989; DeLuchi, 1993; ETSU, 1994). SPFCs have been tested in a van and a bus in Canada, with hydrogen from high-pressure cylinders. They are preferred over other fuel-cell designs because of their robustness, long life, low operating temperature, quick startup, and reasonably high power density.

Currently available SPFCs cost well over $1,000 per kW of output, although some analysts predict future costs as low as $20 per kW (Sperling, 1995). For comparison, gasoline engines cost $20 to 40 per kW. A fuel-cell vehicle probably would use the fuel cell to provide a constant power output, with a battery to store power for peak-load requirements. Costs per kilowatt for such systems would be lower than those for a fuel cell sized for peak loads. Nevertheless, given the technical and cost improvements required, fuel cells are unlikely to be in widespread use for cars before 2025. They will face institutional and other challenges similar to those confronting alternative fuels in general. However, if the various barriers to their use can be overcome, fuel-cell cars could be the predominant mode of motorized travel by 2050.

Many hybrid concepts have been suggested and demonstrated, combining the advantages of electric drives and internal-combustion engines. One approach involves using a low-powered fuel-burning engine to run a generator that provides a constant supply of electric power (see, e.g., Lovins *et al.*, 1993). This is either used directly to power electric motors or fed to a peaking storage device, which might be a battery or flywheel. A major theoretical advantage of such a system is that the engine can operate under its optimum speed and load, and braking energy can, in principle, be recovered and stored. In principle, energy savings in urban driving could amount to 40 to 60%. However, with current technology, energy savings are likely to be very small because efficiency is constrained by energy losses in the electric generator, storage device, and motor; matching the engine and electrical storage device to real on-road power requirements is difficult; and existing batteries are unable to recharge at the rates required to store a useful portion of energy from the engine and from braking. Flywheels may be more appropriate for this purpose, and the concept is under development. Hybrid technology is not likely to achieve substantial market share in the short term without government intervention, in view of the high overall cost of an electric motor, control system, and battery or other storage device. It might be feasible to produce hybrid vehicles on a competitive commercial basis some time between 2005 and 2025.

Direct electric power has long been used in light-rail systems and trolleybuses, as well as in electric trains. Urban bus and light-rail routes involve low speeds and frequent stops. In these circumstances, the features of electric drives are very attractive—in particular the capability for regenerative braking, the avoidance of energy use when stationary, and the absence of emissions at the point of use.

Trolleybuses are in use in numerous cities throughout Europe. They are lighter than battery buses because they do not have to carry an electricity source. They also allow for a more efficient use of grid electricity and a better capability for regenerative braking. Whereas the overall efficiency from grid electricity to motive power for a battery-powered vehicle is about 55%, that of a trolleybus is about 75 to 85%.

Several proposals exist for personal passenger-vehicle systems based on direct electric power. These range from cars supplied with electricity via induction coils placed under the road surface to monorail systems with vehicles powered by linear motors. Some designs involve the use of computer-controlled vehicles for public use. Others provide for the use of private cars off the system using batteries or other power sources. Such systems are potentially an efficient means of using electric power for personal transport.

21.3.5. High-Speed Trains

High-speed trains can have higher energy use per seat-kilometer than traditional trains but much lower energy intensity than cars or aircraft at typical load factors. Their role in greenhouse gas emission reduction is subject to debate and will depend heavily on the situations in which such trains are used: They may attract passengers without reducing the use of other modes, resulting in higher overall energy use and greenhouse gas emissions. Nevertheless, high-speed rail lines between Paris and Lyons in France and between Madrid and Seville in Spain have been remarkably successful in attracting business from the roads and the airlines, and have been profitable.

An alternative to the high-speed train is “maglev”: trains that are levitated on a magnetic field rather than having wheels in direct contact with tracks. The only existing maglev systems in use are small-scale local shuttle or transit systems. Maglev trains may have some energy-efficiency advantage compared with wheeled trains at a given speed, but analyses differ on this (Schäfer *et al*., 1992). Rolling resistance (25% of energy use in a normal high-speed train) is avoided, but energy is required to power the magnets. The main advantage of maglev trains is that they can operate at higher speeds than wheeled trains; the Transrapid line to be built from Hamburg to Berlin will operate at up to 450 km/h. This means that they can compete with air travel over longer distances than existing high-speed trains—potentially as far as 1,500 km. Maglev trains have the disadvantage compared with high-speed trains that, unless provided with auxiliary wheels, they cannot use existing stretches of track to penetrate urban areas and serve destinations without new infrastructure.

21.3.6. National and International Technology Policy

Governments can take various kinds of action to influence technology development and deployment. Some, such as basic research and development, are aimed at bringing technology to the point where industry can further develop it to produce new products and sell them in the market. Others, such as fiscal and regulatory incentives and funding for demonstration programs, are aimed at encouraging industry to carry out its own research or to market different products and encouraging consumers to buy them.

Research and development is usually difficult to plan on a rational, economic basis. Scientific breakthroughs are inherently unpredictable, and even if a technology is successfully developed its market success is also unpredictable. Fundamental research often depends for its existence on some form of government intervention, whether this is direct funding, tax exemptions for firms undertaking research and development, or information brokering. Meanwhile, national investment in research may be justified on cultural grounds as well as on economic grounds. Contributions to international scientific ventures often are motivated by international relations as well as by an interest in cost-effectiveness.

Important areas for fundamental research relating to transport technology include recyclable materials for cheap, robust, lightweight vehicles; materials with special properties for high-efficiency engines, turbines, flywheels, and so forth; advanced conversion technology for liquid fuels from biomass; electrochemistry for batteries and fuel cells; power electronics for electric-propulsion-system management; power-transmission technologies for vehicles powered directly from the mains; and information technology for vehicle and traffic optimization. There is also a need for social and economic research—for example into consumer behavior and choice, including attitudes toward new technology.

Interventions in the market may have the advantage that government does not necessarily have to attempt to “pick winners” among technologies or bear the risk of investment in research that may not bear fruit. However, this risk does have to be borne by manufacturers that wish to remain in the market and have to respond to the government’s intervention. One example of a technology-forcing intervention is the California Air Resources Board’s strategy for encouraging the development of zero-emission vehicles (see Box 21-3). Meanwhile, a strategy of announcing a timetable for gradually tightening standards or increasing fiscal incentives, aimed at reducing greenhouse gas emissions, will encourage industry both to introduce currently available technology and to develop new technology.

21.4. A Transport-Policy Perspective on Greenhouse Gas Emissions

While technical changes can, in theory, reduce greenhouse gas emissions by 80% or more for a given transport activity, such changes are not occurring under current market conditions. Meanwhile, in most countries, transport-activity growth is faster than the rate of energy-intensity improvement.

Section 21.4 explores different viewpoints that influence policymaking, identifies areas of transport policy that can influence

Box 21-3. CARB Strategy for Encouraging Zero Emissions Vehicles

California's urban air-quality problems have long been recognized as more severe than in other regions of the United States. The California Air Resources Board (CARB) introduced the Clean Fuels and Vehicles Plan in September 1990. The plan imposes progressively lower emission standards on vehicles from 1994 onward. VOC emissions must be cut 80% below 1994 levels by 2000.

Under the legislation, vehicles are given one of four new emission classifications: transitional low-emission vehicle, low-emission vehicle, ultra-low-emission vehicle, or zero-emission vehicle. Manufacturers' sales-weighted VOC emissions calculated from their sales of each vehicle type must not exceed a prescribed level in a given year. A banking and trading system permits manufacturers to earn marketable low-emission credits.

CARB's specifications for reduced summer gasoline volatility, elimination of lead, and the use of detergent additives came into force in 1992. Further tightening of gasoline specifications is expected.

Alternative fuels are being promoted by CARB and through the federal California Pilot Vehicle Program. The fuels are expected to help satisfy low-emission requirements. They include M100, M85, CNG, and LPG. At least 90 Southern California filling stations must supply alternative fuels by 1994, rising to 400 by 1997. From 1994 onward, 200,000 new low-emission vehicles per year (about 10% of the state's new-car fleet) must be sold in California. Alternative-fuel use is also being encouraged through tax exemptions.

Electric vehicles will be required to satisfy the zero-emission-vehicle requirement from 1998 onward. They will have to make up a minimum of 2% of annual new-car sales by companies selling more than 30,000 cars per year in California; the share is scheduled to rise gradually to 10% by 2003. Electric-vehicle use in California is likely to result in greenhouse gas emissions significantly lower than those associated with gasoline-vehicle use because much of the power generation in the state is from non-fossil-fuel sources or natural gas.

greenhouse gas emissions, and examines policy options for emission reduction.

Transport policymakers' central aims are usually to maximize mobility and access to services, enhance economic activity, and improve safety. These aims have to be balanced with energy and environment goals, especially those of reducing urban air pollution and greenhouse gas emissions. At the same time, policymakers have to consider the political acceptability of their measures, as well as their ease of implementation and their effects on equity and social welfare generally.

21.4.1. Stakeholders and Viewpoints in Policymaking in the Transport Sector

Policymakers and other stakeholders typically are involved in the transport sector in several different ways:

- Local public-transport authorities or firms make decisions regarding public-transport scheduling and investment, aiming to maximize fare revenue, minimize costs, and in some instances to provide a minimum level of service.
- Local or municipal authorities make many decisions regarding transport policies, urban road layout, parking facilities, urban traffic management, and facilities for walking and cycling. Their objectives include improving access; reducing road congestion, accidents, and noise; and, more recently, reducing air pollution—all within a fixed budget.
- Decisions regarding the development of highways, railways, and other transport infrastructure are usually made by national transport ministries, which often define the parameters within which local transport authorities work and provide funds for infrastructure and services. Transport ministries have traditionally aimed to maximize mobility and access for both freight and motorized passenger transport in a cost-effective manner, sometimes including social costs associated with congestion, accidents, noise, and air pollution.
- Vehicle emission standards are often negotiated between government departments of environment, transport, and industry. Emission standards for road vehicles and aircraft (ICAO, 1993) are, in many instances, agreed between governments—in consultation with industry and other interest groups—with the mediation of intergovernmental organizations.
- Vehicle and fuel taxes are of interest to transport, industry, and energy departments, but they often are determined by finance ministries.
- Transport research and development is undertaken by a range of interests, including various government departments, universities, and other research institutes, as well as vehicle manufacturers and transport-system operators.

- Transport-system users make day-to-day decisions regarding vehicle purchase and utilization but normally have limited influence on transport policy.

Differences in the priorities of decisionmakers have much to do with differences in training, approach, and worldview associated with the professions most involved in each area of policy. Dimitriou (1992) provides a characterization of fields of expertise:

- Engineers often emphasize the operational efficiency of transport systems and usually offer solutions based on technology or the design of infrastructure.
- Economists usually emphasize economic efficiency, aiming to maximize the benefits minus the costs of the transport system. Their solutions tend to focus on improving the functioning of the market.
- Other social scientists, such as sociologists, political scientists, anthropologists, and development planners, are less likely than engineers or economists to use formalized concepts of optimization. Their solutions are likely to focus on institutions, community involvement, and consultation.
- Physical planners (architects, city planners, and transport planners) tend to view transport issues as part of a wider picture of urban development. Their solutions tend to relate to the spatial organization and design of infrastructure.

Politicians, environmentalists, and other interest groups (including transport-user associations) may draw on a variety of these viewpoints and solutions in identifying their preferred transport strategies. To bring transport policy to bear on the aim of reducing greenhouse gas emissions, it will be important to bring the different professions and viewpoints together to develop robust strategies that satisfy all of their criteria and make use of all of their insights and techniques.

21.4.2. Planning, Regulation, and Information Measures

Traditional approaches to transport planning have concentrated on providing sufficient roads to carry projected volumes of traffic and on smoothing the traffic flow. Many planners now recognize that it is impossible to provide sufficient roads to carry unrestrained projections of traffic in urban and perhaps some interurban areas, and that extra road provision can stimulate traffic growth, leading to congestion elsewhere (Goodwin *et al*., 1991). Increasingly, the objectives of transport are seen as moving people and providing access to services, jobs, and homes rather than moving vehicles. The planning emphasis is on alternatives such as improving the traffic flow, encouraging the use of public transport and nonmotorized transport, and discouraging car use.

Improving the traffic flow in cities to reduce stop-start driving can reduce the energy use per vehicle-kilometer as well as emissions of local pollutants (Ang *et al*., 1991; Hausberger *et al*., 1994; Joumard *et al*., 1990; Tanja *et al*., 1992). Many measures to improve traffic flow, such as computerized traffic-signal control, actually increase the capacity of the road network so that traffic volumes may increase unless traffic levels are restrained in some way. Provided that traffic is restrained—for example, by limited parking provision, tolls, or fuel taxes or through constraints on vehicle access—the introduction of computerized signal control may lead to energy savings of 10 to 15% (Ang, 1992).

Encouraging public-transport use and nonmotorized modes. Travel by bus, train, foot, or bicycle usually involves lower greenhouse gas emissions per km than travel by car (see Section 21.2.5) and also can reduce wider social and environmental damage. People's willingness to use low-energy-intensity transport modes depends partly on the quality of travel by those modes. Planners can influence this by providing infrastructure, such as pedestrian and cycle paths, bus lanes, and railways. Public-transport use can be increased by providing better information about services, reducing fares, and improving the quality of the service. Flexible services, such as shared taxis and "dial-a-ride" minibuses, can play a role. Improvements in public transport rarely have proved to be an effective means of stemming the rise in private-transport use unless combined with measures to limit the attraction of car travel, such as access and parking constraints. Experience in Hannover, Zurich, and other cities indicates that such combined approaches can be successful (Brög, 1993; Goodwin, 1985; Ott, 1993). Lessons learned in these cities may have particular relevance for cities in Central and Eastern Europe (Suchorzewski, 1993).

A UK study in the 1970s found that the degree of hilliness and perceived safety were the main determinants of the share of trips by bicycle in a number of towns (Rowell and Fergusson, 1991, quoting Waldman, 1977). While it is hard to modify hills, safety and security are important keys to maintaining and promoting levels of cycling and walking. Safety for cyclists can be improved by providing physically separated cycle lanes on and off roads and by giving cyclists priority over motorized traffic at junctions. Security against cycle theft can be improved by providing appropriate parking facilities. Safety for pedestrians can be improved by providing and maintaining footpaths, providing lighting at night, and ensuring safe means of crossing roads. For rickshaws and carts, similar facilities are effective—in particular separated lanes on roads so they do not have to compete for and disrupt traffic.

Discouraging car use. Cities that have succeeded in promoting nonmotorized and public-transport use have done so partly by making car access more difficult. This has been accomplished in two main ways: pedestrianization of town centers, and "traffic calming"—most frequently in residential streets—with a combination of engineering, design, psychological, and architectural methods to slow vehicles down, alter the "balance of power" away from vehicles and toward pedestrians, and restrict car use.

Approaches include the conversion of existing road space to cycle and bus lanes or "high occupancy" lanes for shared cars;

restrictions on parking; limits on vehicle access to certain city areas or on movement between parts of a city; and motor vehicle-free zones. Restrictions on vehicles can result in evasive actions by drivers that lead to higher levels of traffic, energy use, and pollution in other parts of the city. However, if measures are planned well, residents and local businesses frequently are pleased with the results (Ott, 1993). The best schemes have resulted in increased safety, a more pleasant street environment, and improved retail trade (Hass-Klau, 1990, 1993). Poorly designed schemes can make emissions worse (for example, speed bumps that are too far apart encourage acceleration and deceleration), but in general these policies are seen as reinforcing the attractiveness of public transport and deterring traffic growth. The effectiveness of a strategy may hinge on consultation with the local community on its preferred approaches. Flexibility also can be an essential component: Counterproductive effects cannot always be anticipated, and it is important to monitor the results of measures to identify necessary changes.

Urban structure affects the distance people travel to meet their needs. Travel patterns may be influenced by many factors, including the size of settlements, proximity to other settlements, location of workplaces, provision of local facilities, and car ownership. Changes to settlement planning and regulation have been proposed as means of reducing car use and encouraging public transport and nonmotorized travel (Newman and Kenworthy, 1989). However, the link between settlement patterns and energy use for transport is controversial, and analysts have produced conflicting recommendations (Banister, 1992). While there does appear to be an inverse correlation between urban density and transport energy use (Armstrong, 1993), experts disagree on the desirability and effectiveness of densifying existing dispersed populations to reduce energy use. The trend toward lower urban density may result from people purchasing homes in locations with lower land prices where they have an improved quality of life. Attempts to reverse this trend may depend on addressing the welfare implications directly through measures to improve the physical and social environment in high-density areas. Policies that directly discourage the use of energy-intensive transport modes are likely to be more effective in reducing energy use.

In the short term, the greatest potential for urban planning to affect transport energy use is in rapidly developing cities where the car is still a minority transport mode. In such cities, infrastructure development focused on provision for cars and trucks could accelerate the growth in use of these modes and the decline in use of less energy-intensive modes. Provision for nonmotorized modes in new infrastructure is an important enabling factor for policies to encourage the use of these modes and discourage car use.

In the long term, around 2025 to 2050 and beyond, changes in travel culture and lifestyle combined with changes in urban layout might lead to substantial reductions in motorized travel in North American and Australian cities. The potential reduction in European cities is smaller because a higher proportion of access needs already are met by walking and cycling.

21.4.3. National Transport Policy

National transport policymakers influence the decisions taken by local transport and urban authorities through regulations, grants, planning guidelines, provision of information, and other means. National governments can contribute to local initiatives by providing coordination, information, and encouragement to local authorities considering measures that affect energy use and greenhouse gas emissions.

National governments may have a responsibility for a variety of regulatory measures that can influence vehicle fuel economy and greenhouse gas emissions. These measures might include speed limits, vehicle emission standards, and maintenance checks, as well as more direct measures, such as vehicle fuel-economy standards (see Box 21-4).

Drivers are more likely to change their vehicle choices and driving behavior in ways that reduce environmental impact if they understand that impact and are motivated to reduce it (Jones and Haigh, 1994). National measures can include advertizing and information campaigns, as well as the incorporation of energy- and environmental-awareness elements in the school curriculum and driver training. Standards in advertizing also are normally set at a national level. Information-based policies are likely to be most effective if they are maintained over long periods and are linked to changes in fiscal and regulatory policy.

National governments may have a direct involvement in the provision of rail and bus services through ownership, subsidies, franchises, and regulation. Many of the means of encouraging passengers to use these services are similar to those that apply to urban public transport; the most effective measures are likely to be those that discourage car use.

National transport policymakers can influence freight-transport patterns through measures applied to road-freight vehicles and their use. Vehicle licensing fees are often a significant element in road-haulage costs and can be used as a measure either to discourage road freight or to encourage the use of vehicles with lower power-to-weight ratios. Vehicle standards, including safety requirements, weight limits, and emission standards, also can influence vehicle choice and mode choice.

Where goods can be shifted from road to rail, the energy saving per tonne-kilometer can be zero to 50%. A variety of approaches have been developed to allow freight to be transferred easily between road and rail. The greatest energy savings are likely to be obtained with multimodal containers that can be moved between truck trailers and flat rail wagons. Cost savings can be significant for very long trains (100 wagons or more) traveling long distances because driver costs are greatly reduced.

21.4.4. Alternatives to Travel

Many of the needs that are met by the transport system could, in principle, be met by other means. Telecommunications, for

Box 21-4. Fuel-Economy Standards

In theory, the most economically efficient way of reducing car fuel consumption is through fiscal measures (which are discussed in Section 21.4.5). Higher fuel taxes tend to lead drivers to economize through driving more carefully, reducing the distance they drive, and choosing more energy-efficient vehicles. However, fuel taxes are difficult to impose in some countries. Consumers often have inadequate information about the cars they are buying and may not respond optimally to the price change. More complex price-based measures, such as taxes (or subsidies) linked to vehicle fuel economy, may be more effective in the long term, because they give consumers a direct incentive at the time of purchase to choose an energy-efficient vehicle.

An alternative or complement to taxation is to use regulations to require car manufacturers to sell more energy-efficient cars. There are advantages and disadvantages to this approach. Standards avoid the large transfer payments that might be required with a tax approach, given the low price elasticity of transport-fuel demand. On the other hand, improving fuel economy can lead to reduced driving costs and increased travel (the "rebound effect"), so that, while energy use and greenhouse gas emissions may be reduced overall, other environmental and social impacts of transport may be increased. Vehicle standards are sometimes criticized because they provide industry with insufficient flexibility to find the best technical solutions to complex problems. In the U.S. Corporate Average Fuel Efficiency (CAFE) program, this problem is partly addressed by allowing manufacturers freedom to determine the fuel economy of individual models, provided that the average fuel economy of their total sales of cars meets the standard. Companies that do not meet the required average fuel economy have to pay fines. Meanwhile, very-high-consuming cars are subject to a "gas guzzler tax," which is effective in limiting the fuel economy of cars sold (DeCicco and Gordon, 1995). A "sipper rebate" for very-low-consuming cars has been discussed, though never enacted. Manufacturers of alternative-fuel vehicles can claim credits against their corporate-fuel-economy average, allowing them to produce cars with higher fuel intensity.

While CAFE has generated considerable debate in the United States, Greene (1990) finds that the policy was a real constraint on vehicle manufacturers from 1978 to 1989 and that it had twice as much effect on car fuel economy as fuel price. However, the rebound effect was such that somewhere between 5 and 30% of the fuel-economy gain was lost through increased mileage (Berkowitz *et al*., 1990; Greene, 1992; Jones, 1993).

example, might allow many trips to be avoided. The growth in service industries and associated office-based employment means that many types of work could be carried out in the home or in small regional offices connected to central offices via computer systems, faxes, and telephones. Similarly, an increasing number of transactions can be carried out through telecommunication systems. Much of the existing transport infrastructure in Europe and the United States was developed before such possibilities existed. Thus, culture has developed around travel to work, to shop, and for other purposes. Conversely, in many developing countries, telecommunication infrastructure is likely to precede efficient transport infrastructure. This offers opportunities for cheap access to employment and services that would not otherwise be available.

Telecommunications are likely to substitute for travel only to a limited extent. Indeed, improved communications may encourage more travel, as people develop closer working and social relationships over longer distances. At the upper end of the income scale, mobile telephones and electronic mail allow executives to maintain communication with their offices wherever they are, giving them freedom to travel while keeping in touch. However, at the other end of the scale, telecommunication systems may provide a means to economic growth without the traditional associated costs in infrastructure and the social and environmental burdens of rising levels of transport activity. In the long term, virtual-reality-based communication might replace business and other travel, although the extent of this possible substitution cannot now be predicted.

21.4.5. Economic Influences and Fiscal Measures

Roads in most countries are built and maintained by governments and are available, subject to regulations mainly related to safety, for anyone who wishes to use them. While the costs of road provision are recovered through fuel or vehicle taxes in some countries, in others taxes are insufficient to cover the costs. MacKenzie *et al*. (1992) estimate that road users in the United States pay only 60% of infrastructure costs through taxes and fees. Apart from tolls for special kinds of infrastructure (bridges, tunnels, and motorways), direct payment for road use, or "road pricing," occurs only in a few, mostly experimental, situations.

In Europe, vehicle purchases constitute about 90% of total investment in road transport, with infrastructure investment only 10% (ECMT, 1992). Infrastructure in rail transport accounts for 65 to 80% of total investment, with rolling stock only 20 to 35%. There is no straightforward way to allocate infrastructure costs between freight and passenger transport, but indicative costs for roads in Europe would be US$0.015 to 0.025 per passenger-km and US$0.1 to 0.2 per tonne-km (based on ECMT, 1992). These represent about 5 to 10% of passenger transport costs and a third of freight transport costs, respectively. In Western Europe, direct government expenditures on infrastructure related to car use are usually fully recovered from users through fuel or other taxes, although these taxes may not be explicitly intended to provide for a "road fund" as in the United States. Infrastructure costs for road-freight transport in some countries may not be fully recovered through taxes and fees. Charges reflecting these costs might add 10% to 30% to road-freight costs (Blok, 1991).

Most studies find that, when social and environmental damage are included, the costs not paid in money outlays by car and truck users have about the same order of magnitude as the costs paid (Button, 1990; DeLuchi *et al*., 1994). Table 21-7 shows results based on several studies in OECD countries. The work by Button (1990) is based on earlier work by Quinet.

From the point of view of transport and environment policy, it is important to understand which of the costs of transport are born by users and which are not. Where users do not bear the full cost of transport, they are likely to make more use of transport services than is economically efficient (Button, 1994). DeLuchi *et al*. (1994) find that, in the United States, motor-vehicle users bear about 70% of the overall cost of vehicle use (see Table 21-8). Most of the remainder relates to free parking provision and accident damage not paid for by insurance.

Environmental external costs amount to $0.02 to $0.1 per km driven by cars (Bleijenberg, 1994; DeLuchi *et al*., 1994; IEA, 1993a; Kågeson, 1994; MacKenzie *et al*., 1992). Kågeson (1994) gives total external costs for Germany in 1993 of 0.012 European Currency Unit (ECU) (US$0.015) per tonne-km in trucks. External costs for trains are about 0.005 ECU (US$0.006) per passenger-km and 0.004 ECU (US$0.005) per tonne-km.

Table 21-7: *Estimates of total social cost (as percentage of GDP) of transport in OECD countries.*

Cost Item	Road[a]	Other Modes[a]	All Transport[b]
Noise	0.10	0.01	0.3
Local Pollution	0.40		0.4
Total Pollution			1–10[c]
Accidents	2.00		1.5–2
Total Travel Time	6.80	0.07	8.5 (of which 2–3 is due to road congestion)
Use Expenditure	9.00	0.30	–
Total	**18.30**	**4.71**	**–**

[a] Button, 1990.
[b] Quinet, 1994.
[c] This depends on the assumed damage costs associated with global climate change.

Table 21-8: *Costs of motor vehicle use in the United States (DeLuchi et al., 1994).*

Cost Item	Percentage of Driving Costs
Money Costs of Driving	**40–45**
Paid by user	30
Public roads and services	5
(not recovered through taxes and fees)	(2)
Private sector costs not paid by user (mostly unpriced parking)	5–10
Non-Money Costs of Driving	**55–69**
Borne by user (includes travel time)	40
Not borne by user (mostly accidents)	15–20
(environmental effects on health)	(2–10)
Subtotal—due to road dust	1–7
Subtotal—due to fuel/exhaust emissions	1–3

The incorporation of nonmoney costs of driving as user fees or taxes is one of the most commonly discussed measures to reduce traffic congestion and pollution. The response of transport energy demand to costs, especially fuel prices, has been extensively studied since the early 1970s. Researchers find that:

- A 10% increase in fuel prices results in a 1 to 6% short-term reduction in demand, according to most studies (Dahl and Sterner, 1991; Fowkes *et al*., 1993a; Tanja *et al*., 1992), although the effect of price increases is not symmetrical with the effect of price decreases (Dargay, 1993). In the long term, fuel-price increases encourage the use of more energy-efficient vehicles, and a 10% increase in gasoline prices can lead to a 5 to 16% reduction in demand. The response to fuel price falls as incomes rise, all else being equal (Goodwin, 1992; Greening *et al*., 1994). Where several fuels compete and can be used in the same vehicles, small relative price changes can have a large effect on fuel choice (Greene, 1989; IEA, 1993a).
- A 10% increase in car price leads to a 1 to 5% reduction in total fuel consumption (Tanja *et al*., 1992), but there is a complex interaction between the price of fuel, the prices of new and second-hand cars of different sizes, car ownership, and car use (Mogridge, 1983). Differential vehicle taxes related to energy efficiency can be one of the most economically efficient means of encouraging the use of energy-efficient vehicles (DeCicco and Gordon, 1995).
- Car and truck use is not affected noticeably when the costs of other transport modes fall, although rising public-transport and rail costs may encourage users to switch modes. Rail and bus travel do depend strongly on the cost of car travel. Studies of the effects of transport costs have been carried out for different transport modes in many situations (Oum *et al*., 1990;

Fowkes *et al*., 1993a, 1993b). In the United Kingdom, these studies indicate that a 10% increase in bus or urban metro fares reduces patronage by 3 to 4% in the short term and around 7% in the long term.

- Various factors in addition to transport costs and income affect travel activity, including household size, the occupation of the head of the household, household makeup, and location (Hensher *et al*., 1990; Jansson, 1989; Walls *et al*., 1993). People in higher-skilled occupations, requiring higher levels of education, are more price- and income-responsive in their transport energy demand than people in lower-skilled occupations (Greening and Jeng, 1994; Greening *et al*., 1994). Families are more price- and income-responsive in the early years of childrearing than in the later stages.

Road-use charges can, in theory, help allocate available road space in the most economically efficient way. Road-use fees can be used to reduce both the explicit subsidies for road building and maintenance and the implicit subsidies associated with the externalities of driving. By increasing the variable cost of driving, such changes can encourage travelers to share vehicles, travel shorter distances, or use alternative modes. They are expected to be most effective when charged to the driver at the time and point of use. Polak *et al*. (1994) have analyzed the long-term impact of the Area Licensing Scheme in Singapore and found that a 10% increase in the cost of peak-period travel resulted in a 7% reduction in peak traffic in the short run and a 12% reduction in the long run. Toll rings in the Norwegian cities Oslo and Trondheim have reduced traffic by 4 and 8%, respectively (Polak and Meland, 1994; Ramjerdi, 1992).

Parking fees can be an important component of any transport strategy. In many cities, employees are provided with free car parking at work. Studies in the United States (DOE, 1994) indicate that offering people in large cities the cash value of their parking place as an alternative would raise the effective cost of their trip to work by 116%. Of those offered the “cash-out,” 23% would accept it in the long term and choose alternative transport modes to commute to work.

Many other market-based strategies have been proposed, ranging from “pay at the pump” insurance charges collected through filling stations to fuel-consumption permits that would be tradable between manufacturers.

Revenues from charges imposed on cars and trucks can be used to subsidize transport modes with lower social costs and greenhouse gas emissions. Nevertheless, while keeping fares low may maintain existing ridership, it is unlikely to attract many additional users from private transport without other measures.

21.4.5.1. Vehicle Taxes

Vehicle taxes are traditional sources of government revenue and controls on imports. Cars usually are taxed at a higher rate than buses or trucks—a policy that promotes commercial activity as opposed to private car ownership. Many countries base purchase taxes or license fees on engine size or vehicle weight; this can be a powerful instrument to encourage the purchase of small, energy-efficient cars. In some African countries, taxes are used to discourage imports of second-hand vehicles, while, in others, vehicles older than five years are banned (Davidson, 1993).

Recently, several governments have considered the possibility of using “feebates”: taxes for vehicles with high fuel consumption along with rebates for vehicles with low fuel consumption. Such a scheme is in operation in Ontario, Canada, with a tax ranging from Can$75 to 4,400 (about US$55 to 3,300) on new cars with fuel consumption over 6 L/100 km sold in the province; purchasers of cars with fuel consumption under 6 L/100 km receive a Can$100 (about US$75) rebate (Canada, 1994).

21.4.5.2. Fuel Taxes

Road-transport fuel taxes mostly are used as a means of revenue raising, often to cover the costs of infrastructure and other transport services. Differential taxes are used in many countries to encourage the use of cleaner fuels, such as unleaded gasoline and low-sulfur diesel, or alternative fuels, such as LPG, CNG, and alcohols. Taxes are usually higher on gasoline than on diesel, a cross-subsidy from car users to truck operators that has a side effect of encouraging the use of diesel cars. The implications for CO_2 emissions are not clear: Diesel cars on average have lower CO_2 emissions per km than gasoline cars, but since the fuel is cheap, their owners will tend to drive their cars farther than do gasoline car owners. On the other hand, if gasoline taxes are higher than they otherwise would be, gasoline-car owners will tend to drive less.

In the case of air travel, contracting states of the International Civil Aviation Organization have agreed on a policy that fuel used for international operations should be exempt from all taxes (ICAO, 1994b). The world average price for aviation fuel for international scheduled services in 1991 was US$0.2/L (ICAO, 1994c). A 10% increase in fuel prices would lead to roughly a 1.5% increase in total passenger-travel costs and might be expected to lead to roughly a 1% short-term decrease in travel (based on ICAO, 1992). The longer-term effect of fuel prices on aircraft energy efficiency is expected to be quite large because the aviation industry pays close attention to life-cycle cost-effectiveness in considering aircraft design.

21.4.6. Combining Measures

Success in reducing greenhouse gas emissions will depend on using combinations of different measures. This applies in particular to measures that aim to restrict travel or vehicle use. Constraints on car use can have unintended effects; parking controls implemented alone could lead to increased travel (NOVEM, 1992). People making short trips are more likely to be discouraged by parking difficulties than those making long trips. Displacing short-trip traffic creates more parking space for long-trip traffic. Other measures such as fuel taxation, energy-efficiency standards, or more general road pricing could be needed to avoid an increase in energy use for long trips. Similarly, if air travel is constrained by airport congestion, the promotion of high-speed rail as an alternative to short-haul air travel may reduce the number of short-haul flights, opening airport takeoff and landing slots for long-haul flights and encouraging additional energy use.

Combinations of measures, including information and education, are needed to be effective in bringing about modal shifts. Drivers tend to underestimate the costs of car travel (partly because they only notice fuel costs) and overestimate the cost and inconvenience of travel by public transport (Brög, 1993).

Many cities have attempted to implement integrated transport policies, using a wide range of measures to reduce traffic and encourage the use of more energy-efficient, low-emission vehicles (ECMT/OECD, 1995). Usually, these attempts are hard to assess because it is difficult to judge what would have occurred if the policies had not been implemented. One analysis of the effect of the transport policy in Singapore is summarized in Box 21-5.

Box 21-5. Singapore: Effects of Integrated Transport Policy

Singapore is a small island state with 2.8 million people in an area of 633 km^2 (44/ha). Since the early 1970s, it has adopted a variety of measures to control the traffic problems associated with high population density and rapid economic growth.

Computerized traffic-signal systems have been widely implemented in the central business district (CBD).

The *Area Licensing Scheme* (ALS), a road-pricing scheme introduced in 1975, was aimed at reducing morning peak traffic in the CBD. Drivers were required to purchase windscreen stickers, which were checked on entering the ALS zone. The program immediately reduced the number of vehicles entering the zone during the morning peak and shifted many people's morning commute habits. The success of the scheme led to its extension to include evening peak hours in 1989 and then to the whole day in 1994. In 1996, an electronic road-pricing system will replace the ALS.

The *Weekend Car Scheme* was introduced in 1991. Owners of cars registered under the scheme can normally drive only on weekends and receive a rebate on vehicle registration fees and import duty. They can purchase day licenses to operate their cars during the week in peak or off-peak hours.

Fiscal measures, including high import duties, vehicle registration fees, and annual road taxes, have been implemented to discourage car ownership. In 1994, import duties and registration fees amounted to 195% of car import values.

The *Vehicle Quota System* was introduced in 1990, limiting new registrations of cars and other vehicles. New-vehicle buyers have to bid for quota allocations in a monthly public auction.

Road tax increases with engine capacity, encouraging the purchase of small, energy-efficient cars.

Fuel tax is approximately 40 US¢/litre.

Public transport is of high quality, with buses providing a 20 km/h average service. There is a 67-km mass rapid-transit system, with more than half of Singapore's homes and work locations within 1 km of the route.

The *road network* has been upgraded and the capacity expanded constantly to provide more efficient transport links and to maximize the effectiveness of the road system.

Settlement planning is systematic, with colocation of homes, shops, schools, recreational facilities, factories, and offices in each of seventeen new towns or housing estates.

The result of this combination of measures on traffic and energy use has been estimated by Ang (1992).

Table 21-9: *Estimated 1990 fuel consumption in Singapore without car constraint policies (in millions of L).*

	Gasoline	**Diesel**
Actual Consumption	741	465
Impact of not having policy		
– Passenger traffic increase	+153	
– Modal shift	+218	-84
– Shift to larger cars	+52	
– Traffic congestion	+122	+77
Consumption without Policy	1286	458
Estimated Impact of Policy on Consumption	-42%	+2%

Source: Ang, 1992, 1993.

As the Singapore example illustrates, measures of many different types can be coordinated to achieve one set of policy objectives. Many other examples can be found, including Curitiba, Zurich, Hannover, Oxford, and Portland, Oregon, where coordinated policies have been used to slow or even reverse the growth in car use (Rabinovitch, 1993; Brög, 1993; Ott, 1993; ECMT/OECD, 1995).

Appropriate mixes of policies will vary between cities and countries. Birk and Zegras (1993) provide case studies of four Asian cities to illustrate different approaches to an integrated strategy for managing the environmental effects of transport. They summarize the potential for policy coordination in a matrix, on which Table 21-10 is based.

21.4.7. Implementation

Greenhouse gas emission reduction in the transport sector, more than in any other sector, depends on obtaining cooperation among the various stakeholders or interest groups who are able to take action or who might be affected by policies. Almost all members of society and all organizations have some involvement in the transport system. There are numerous overlaps between transport policy and other areas of government policy. Inevitably, there will be some clashes of interest, but there also will be areas of agreement. Where government departments and other institutions, organizations, and interest groups can agree on economic, environmental, and social aims, there will be more scope for a coordinated approach to transport policy. Coordination among regions is also important.

The following steps are important in any attempt to implement transport policies.

Understanding the current system and its evolution. Ideally this step would include:

- Carrying out surveys of vehicle flow rates and occupancies, analyzing the records of commercial transport operators, and requesting them or requiring them to keep records
- Employing economists and social scientists to evaluate the importance of different aspects of the transport system to its users
- Establishing processes for consultation with transport users and their representatives
- Examining past trends and evaluating a range of possible futures (a multidisciplinary team is more likely to produce a realistic view of the future than economists, planners, or engineers alone.)
- Considering uncertainty by developing several scenarios against which strategies can be assessed; a robust strategy is one that produces an acceptable outcome in all scenarios.

These activities represent a significant and ongoing commitment of resources to data collection and monitoring that may not always be possible. Information-collection efforts can be approached in stages and have to be designed in the context of the resources available.

Considering a wide range of measures. These might include taxes and fees, alternative-fuel promotion, standards for fuels and vehicles, land-use and infrastructure changes, and promotion of communication technologies.

Evaluation of options would ideally involve a cost-benefit analysis, taking account of all of the social benefits and costs of each measure. While social accounting might become a viable and valuable tool at some time in the future, such techniques are not currently available, and some analysts doubt whether they ever will be—or should be—developed. In the absence of a single quantitative evaluation technique, policymakers can make use of multidisciplinary teams to identify costs and benefits of the various measures and to provide a qualitative evaluation.

Consulting stakeholders. In addition to the importance of stakeholder consultation to obtain information about their needs and activities, measures in the transport sector are more likely to be effective if the people who will be influenced by the outcome are involved in the decision-making process. It is important for stakeholders to be given access to information in the development of transport policy and to be allowed to comment on and possibly correct it as the understanding of the system is developed. In many countries, some form of public consultation is a statutory requirement in the planning process. Consultation can be one of the most valuable steps in decisionmaking more generally, as it may generate new ideas, can help to select the most satisfactory outcomes, and can help to give the eventual users of the system a sense of ownership.

Monitoring and adjustment. Even the best-planned measures are likely to have unexpected outcomes. These occurrences are opportunities to learn and can be dealt with, provided sufficient flexibility is allowed for in the plans. A key to success, therefore, is to plan responsiveness into the decisionmaking process by continuing data collection and analysis to monitor the effects of measures and to allow decisionmakers to make follow-up decisions.

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Table 21-10: *Matrix of transport system improvement options (derived from Birk and Zegras, 1993).*

	Situation		
Options	*High level of existing infrastructure and strong influence on technology*	*Rapidly developing infrastructure and relatively little influence on technology*	*Small towns, relatively simple infrastructure, little influence on technology*
Reducing Vehicle Emissions	Impose vehicle standards or emission-related taxes/rebates Set up inspection and maintenance programs Driver and police training for efficient driving and traffic control Public-awareness campaigns Research, development, and demonstration (RD&D)	Work with other cities and regions to encourage use of improved vehicles Set up inspection and maintenance programs Driver and police training for efficient driving and traffic control Public-awareness campaigns	Work with other cities and regions to encourage use of improved vehicles Set up inspection and maintenance programs Driver and police training for efficient driving and traffic control Public-awareness campaigns
Shifting to Cleaner or Alternative Fuels	Fuel-quality standards, mandates, and taxes Evaluate options for alternative fuels, especially in large fleets including public transport RD&D	Work with other cities and regions to encourage use of cleaner fuels Evaluate options for alternative fuels, especially in large fleets including public transport	Work with other cities and regions to encourage use of cleaner fuels Evaluate options for alternative fuels, especially in large fleets including public transport
Shifting to Modes with Lower Emissions	Provide facilities for nonmotorized modes Consider nonmotorized streets and zones Exclusive bus lanes and bus/tram priority Consider subsidies/fare controls for public transport Consider investment in public transport	Exclusive bus lanes and bus priority Segregate nonmotorized modes Consider possibility of rail conversion to exclusive bus lanes Consider subsidies/fare controls for public transport Consider investment in public transport	Begin to give priority to mass transit in urban transport policy Ensure access to public transport Exclusive bus lanes and bus priority in new development Segregate nonmotorized modes
Transport Demand Management	Regulate or charge for parking Consider vehicle-free zones or restrictions Consider road-user fees, and vehicle and fuel taxes Investigate telecommuting, etc., as alternatives to transport Carpool and high-occupancy vehicle incentives	Restrict on-street parking Consider vehicle-free zones or restrictions Consider road-user fees, and vehicle and fuel taxes Investigate improved communication as alternative to transport Carpool and high-occupancy vehicle incentives	Formal parking controls or fees Consider vehicle-free zones or restrictions Investigate long-term role of road-user fees to manage traffic Investigate improved communication as alternative to transport Car-pool and high-occupancy vehicle incentives
Transport Infrastructure Development	Computerized traffic control Maintain and provide infrastructure for nonmotorized and public transport Segregated nonmotorized and public transport corridors	Improved traffic control Maintain and provide infrastructure for nonmotorized and public transport Segregated nonmotorized and public transport corridors Consider bypasses	Improved traffic control Give priority to public transport and nonmotorized transport in new infrastructure
Land-Use Planning	Consider deemphasizing central zone as major focus of activity Encourage mixed use, nonmotorized/public transport-oriented suburban development Promote mixed use and nonmotorized/public transport access in urban redevelopment Discourage parking provision in development and redevelopment	Desegregate land use; allow mixed use in central business district Promote mixed use and nonmotorized/public transport access in new development Encourage mixed use, nonmotorized/public transport-oriented suburban development	Ensure transport development that enhances rather than hampers economic health of central business district Take transport trends into account and plan transport services in coordination with other development

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